



CAREER ENDEAVOUR

Best Institute for IIT-JAM, NET & GATE

CSIR-UGC-NET/JRF/GATE-PHYSICS

SOLID STATE PHYSICS

Assignment-1

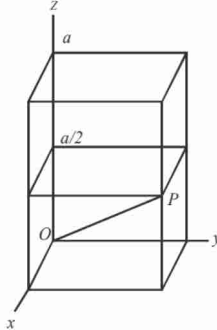
- The packing fraction of a simple cubic lattice is approximately:
(a) 0.74 (b) 0.68 (c) 0.52 (d) 0.34
- Given that r is the radius of the atoms and a is the lattice constant of a solid having a cubic structure, which one of the following relations is true for a body centred cubic structure?
(a) $a = 2r$ (b) $a = 2r\sqrt{2}$ (c) $a = 2r\sqrt{3}$ (d) $a = 4r/\sqrt{3}$
- What is the second nearest-neighbour distance in a face centred cubic lattice whose conventional unit cell parameter is a ?
(a) $a/\sqrt{2}$ (b) $a/2$ (c) a (d) $\sqrt{2}/a$
- The lattice parameters a, b, c of an orthorhombic crystal are related by $a = 2b = 3c$. In units of a , the interplanar separation between the (110) planes is _____ (upto three decimal places) [GATE 2015]
- The target of an X-ray tube is subjected to an excitation voltage V . The wavelength of the emitted X-rays is proportional to:
(a) $\frac{1}{\sqrt{V}}$ (b) $\sqrt{V}$ (c) $\frac{1}{V}$ (d) V
- Silicon has diamond structure with unit-cell-edge $a = 0.542$ nm. The interatomic separation is :
(a) 0.122 nm (b) 0.234 nm (c) 0.383 nm (d) 0.542 nm.
- The total number of Cl^- ions in a unit cell of NaCl crystal is
(a) 4 (b) 2 (c) 8 (d) 10
- The basis vectors of a lattice are $2\hat{i}, \hat{i} + 2\hat{j}$ and $\hat{k}$. The basis vectors of the reciprocal lattice are
(a) $\frac{2}{\pi}(\hat{i} + \hat{j}), \frac{2}{\pi}\hat{j}$ and $\frac{2}{\pi}\hat{k}$ (b) $\pi(2\hat{i} - \hat{j}), \pi\hat{j}$ and $4\pi\hat{k}$
(c) $\frac{\pi}{2}(2\hat{i} - \hat{j}), \pi\hat{j}$ and $2\pi\hat{k}$ (d) $2\pi\hat{i}, \pi(\hat{i} + 2\hat{j}),$ and $\pi\hat{k}$
- A plane in a cubic lattice makes intercepts of $a, a/2$ and $2a/3$ with the three crystallographic axes, respectively. The Miller indices for this plane are
(a) (2 4 3) (b) (3 4 2) (c) (6 3 4) (d) (1 2 3)
- The C/a ratio for an ideal hexagonal closed packed structure is:
(a) $\frac{2}{\sqrt{3}}$ (b) $\sqrt{8}$ (c) $\sqrt{5}$ (d) $\sqrt{\frac{8}{3}}$
- For a closed packed BCC structure of hard spheres, the lattice constant a is related to the sphere radius R as:
(a) $a = 4R/\sqrt{3}$ (b) $a = 4R\sqrt{3}$ (c) $a = 4R\sqrt{2}$ (d) $a = 2R\sqrt{2}$



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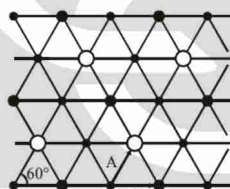
12. In crystallographic notation the vector $\overline{OP}$ in the cubic cell shown in the figure is:



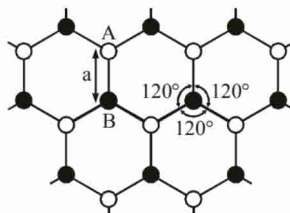
- (a) $[2\ 2\ 1]$ (b) $[1\ 2\ 2]$ (c) $[1\ 2\ 1]$ (d) $[1\ 1\ 2]$
13. The de-Broglie wavelength λ for an electron of energy 150 eV is:
 (a) 10^{-8} m (b) 10^{-10} m (c) 10^{-12} m (d) 10^{-14} m
14. Which is loose packed structure?
 (a) Body centred cubic structure (b) Hexagonal close-packed structure
 (c) Face-centred cubic structure (d) None of these
15. The volume of a primitive unit cell defined by axes $(\hat{k} + \hat{i})\text{\AA}$, $(\hat{i} + \hat{j})\text{\AA}$, $(\hat{j} + \hat{k})\text{\AA}$, is
 (a) $1\text{\AA}^3$ (b) $3\text{\AA}^3$ (c) $2\text{\AA}^3$ (d) $4\text{\AA}^3$
16. The Miller indices of a plane passing through the points $3\hat{a}$, $4\hat{b}$ and $5\hat{c}$, where $\hat{a}$, $\hat{b}$ and $\hat{c}$, are lattice vectors are
 (a) (12, 15, 20) (b) (20, 15, 12) (c) (5, 4, 3) (d) (3, 4, 5)
17. The Miller indices of a set of parallel planes which makes intercepts in the ratio of $1 : \frac{1}{2} : \frac{1}{4}$ is given by
 (a) (421) (b) (124) (c) (122) (d) (142)
18. A simple cubic crystal with lattice parameter a_c undergoes transition into a tetragonal structure with lattice parameter $a_t = b_t = \sqrt{2} a_c$ and $c_t = 2a_c$, below a certain temperature. The ratio of the interplanar spacings of (101) planes for the cubic and the tetragonal structure is
 (a) $\sqrt{\frac{1}{6}}$ (b) $\frac{1}{6}$ (c) $\sqrt{\frac{3}{8}}$ (d) $\frac{3}{8}$
19. The spacing d_{hkl} of the planes (hkl) in a hexagonal crystal is
 (a) $\left[\frac{4}{3} \left(\frac{h^2 + hk + k^2}{a^2} \right) + \frac{l^2}{c^2} \right]^{-1/2}$ (b) $a [h^2 + k^2 + l^2]^{-1/2}$
 (c) $\left[\frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2} \right]^{-1/2}$ (d) $\left[\frac{h^2 + k^2}{a^2} + \frac{l^2}{c^2} \right]^{-1/2}$
20. The inter-planar spacing for (110) plane of a monoatomic FCC crystal of lattice constant $2\text{\AA}$ is
 (a) $1/\sqrt{2}\text{\AA}$ (b) $2\text{\AA}$ (c) $\sqrt{2}\text{\AA}$ (d) $\sqrt{3}\text{\AA}$



21. Which one of the following diffraction techniques has most surface sensitivity?
 (a) X-ray (b) Electron (c) Neutron (d) Optical
22. By using X-ray diffraction one cannot obtain
 (a) crystal structure (b) type of bonding (c) residual stress (d) grain size.
23. A flat surface is covered with non-overlapping disks of same size. What is the largest fraction of the area that can be covered?
 (a) $\frac{3}{\pi}$ (b) $\frac{5\pi}{6}$ (c) $\frac{6}{7}$ (d) $\frac{\pi}{2\sqrt{3}}$
24. A metal suffers a structural phase transition from face-centred cubic (FCC) to the simple cubic (SC) structure. It is observed that this phase transition does not involve any change of volume. The nearest neighbour distances d_{fc} and d_{sc} for the FCC and the SC structures respectively are in the ratio (d_{fc}/d_{sc}) [Given $2^{1/3} = 1.26$]
 (a) 1.029 (b) 1.122 (c) 1.374 (d) 1.130
25. Circular discs of radius 1 m each are placed on a plane so as to form a closely packed triangular lattice. The number of discs per unit area is approximately equal to
 (a) 0.86 m^{-2} (b) 0.43 m^{-2} (c) 0.29 m^{-2} (d) 0.14 m^{-2} [JEST-2014]
26. Consider the crystal structure of sodium chloride which is modeled as a set of touching spheres. Each sodium atom has a radius r_1 and each chlorine atom has a radius r_2 . The centres of the spheres form a simple cubic lattice. The packing fraction of this system is
 (a) $\pi \left[\left(\frac{r_1}{r_1 + r_2} \right)^3 + \left(\frac{r_2}{r_1 + r_2} \right)^3 \right]$ (b) $\frac{2\pi}{3} \frac{r_1^3 + r_2^3}{(r_1 + r_2)^3}$ (c) $\frac{r_1^3 + r_2^3}{(r_1 + r_2)^3}$ (d) $\pi \frac{r_1^3 + r_2^3}{2(r_1 + r_2)^3}$
27. What is the area of the irreducible Brillouin zone of the crystal structure as given in the figure ?



- (a) $\frac{2\pi^2}{\sqrt{3}A^2}$ (b) $\frac{\sqrt{3}\pi^2}{2A^2}$ (c) $\frac{2\pi^2}{A^2}$ (d) $\frac{\pi^2}{\sqrt{3}A^2}$ [JEST 2015]
28. For a 2-dimensional honeycomb lattice as shown in the figure, the first Bragg spot occurs for the grazing angle θ_1 , while sweeping the angle from 0° . The next Bragg spot is obtained at θ_2 given by,



- (a) $\sin^{-1}(3 \sin \theta_1)$ (b) $\sin^{-1}\left(\frac{3}{2} \sin \theta_1\right)$ (c) $\sin^{-1}\left(\frac{\sqrt{3}}{2} \sin \theta_1\right)$ (d) $\sin^{-1}(\sqrt{3} \sin \theta_1)$



29. In a simple cubic lattice of lattice constant 0.287 nm, the number of atoms per mm^2 along the 111 plane is [TIFR 2016]
 (a) 2.11×10^{13} (b) 1.73×10^{13} (c) 1.29×10^{13} (d) 1.21×10^{13} (e) none of these
30. The crystal structure of diamond is:
 (a) fcc with two atom basis of (000) and $\frac{a}{4}(\hat{i} + \hat{j} + \hat{k})$
 (b) simple cubic with two atom basis of (000) and $\frac{a}{2}(\hat{i} + \hat{j} + \hat{k})$
 (c) fcc with two atoms basis of (000) and $\frac{a}{2}(\hat{i} + \hat{j} + \hat{k})$
 (d) bcc with one atom basis
31. In a simple cubic lattice $a = 2 \text{ \AA}$, then planar atomic density of (1, 0, 0) plane is
 (a) $10^{15} \text{ atoms/c.c.}$ (b) $2.5 \times 10^{15} \text{ atoms/c.c.}$
 (c) $5 \times 10^{15} \text{ atoms/c.c.}$ (d) $7.5 \times 10^{15} \text{ atoms/c.c.}$
32. Which of the following crystals cannot be represented by interpenetrating lattices:
 (a) Sodium (b) Sodium chloride
 (c) Cesium chloride (d) Diamond
33. In a simple cubic lattice, the ratio $d_{100} : d_{110} : d_{111}$ is
 (a) $6 : \sqrt{3} : 2$ (b) $6 : 3 : \sqrt{2}$ (c) $\sqrt{6} : \sqrt{3} : \sqrt{2}$ (d) $\sqrt{6} : \sqrt{3} : 1$
34. For an FCC lattice the ratio of $d_{200} : d_{220} : d_{222}$ is
 (a) $\sqrt{3} : \sqrt{6} : \sqrt{2}$ (b) $1 : \sqrt{2} : \sqrt{6}$ (c) $1 : 2 : 3$ (d) $\sqrt{6} : \sqrt{3} : \sqrt{2}$
35. For an NaCl crystal, the cell-edge $a = 0.542 \text{ nm}$. The smallest angle at which Bragg reflection can occur corresponds to a set of planes whose indices are
 (a) 100 (b) 110 (c) 111 (d) 200
36. Consider the atomic packing factor (APF) of the following crystal structures:
P. Simple Cubic **Q. Body Centred Cubic**
R. Face Centred Cubic **S. Diamond**
T. Hexagonal Close Packed
 Which two of the above structures have equal APF?
 (a) P and Q (b) S and T (c) R and S (d) R and T
37. The net magnetic moment of Iron atom in BCC crystal ($a = 2.857 \text{ \AA}$) is $2.2 \mu_B$ ($\mu_B = 9.273 \times 10^{-24} \text{ Am}^2$). The saturation magnetization of Fe at 0 K is
 (a) 1750 Am^{-1} (b) 1750 Am^{-2} (c) 0 (d) 1749.6 kAm^{-1}
38. A metal with body centered cubic (bcc) structure shows the first (i.e. smallest angle) diffraction peak at Bragg angle of $\theta = 30^\circ$. The wavelength of X-ray used is $2.1 \text{ \AA}$. The volume of the PRIMITIVE unit cell of the metal is:
 (a) $26.2 (\text{\AA})^3$ (b) $13.1 (\text{\AA})^3$ (c) $9.3 (\text{\AA})^3$ (d) $4.6 (\text{\AA})^3$
39. Consider X-ray diffraction from a crystal with a face-centered-cubic (fcc) lattice. The lattice plane for which there is NO diffraction peak is:
 (a) (2, 1, 2) (b) (1, 1, 1) (c) (2, 0, 0) (d) (3, 1, 1)



40. In the X-ray diffraction pattern of a sodium metal, which has a bcc structure, the missing reflection planes will be
(a) 101 (b) 011 (c) 020 (d) 100
41. The $\theta - 2\theta$ X-ray powder diffraction pattern of ionic crystals KCl and KBr both of which form fcc structure will have:
(a) same number of diffraction lines with equal intensities
(b) pattern of KBr will have more lines
(c) Pattern of KCl will have more lines
(d) number of lines will be same but their intensities will be different

Statement for Linked Answer Q.42 and Q.43.

The powder diffraction pattern of a body centred cubic crystal is recorded by using CuK_α X-rays of wavelength $1.54\text{\AA}$.

42. If the (002) planes diffract at 60° , then lattice parameter is:
(a) $2.67\text{\AA}$ (b) $3.08\text{\AA}$ (c) $3.56\text{\AA}$ (d) $5.34\text{\AA}$
43. Assuming the atomic mass of the constituent atoms to be 50.94 amu, then density of the crystal in units of kg m^{-3} is:
(a) 3.75×10^3 (b) 4.45×10^3 (c) 5.79×10^3 (d) 8.89×10^3
44. In a powder diffraction pattern recorded from a face-centred cubic sample using x-rays, the first peak appears at 30° . The second peak will appear at:
(a) 32.8° (b) 33.7° (c) 34.8° (d) 35.3°

Statement for Linked Answer Q. 45 and Q. 46.

Lead has atomic weight of 207.2 amu and density of 11.35 gm cm^{-3} .

45. Number of atoms per cm^3 for lead is:
(a) 1.1×10^{25} (b) 3.3×10^{22} (c) 1.1×10^{22} (d) 3.3×10^{25}
46. If the energy of vacancy formation in lead is 0.55 eV/atom, the number of vacancies cm^3 at 500K is:
(a) 3.2×10^{16} (b) 3.2×10^{19} (c) 9.5×10^{19} (d) 9.5×10^{16}
47. For a crystal, let ϕ denote the energy required to create a pair of vacancy and interstitial defects. If n pairs of such defects are formed, and $n \ll N, N'$, where N and N' are, respectively, the total number of lattice and interstitial sites, then n is approximately

[NET Dec. 2019]

- (a) $\sqrt{NN'} e^{-\phi/(2k_B T)}$ (b) $\sqrt{NN'} e^{-\phi/(k_B T)}$
(c) $\frac{1}{2}(N + N') e^{-\phi/(2k_B T)}$ (d) $\frac{1}{2}(N + N') e^{-\phi/(k_B T)}$

Statement for Linked Answer Q. 48 and Q. 49:

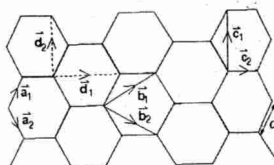
The primitive translation vectors of the face centered cubic (fcc) lattice are

$$\hat{a}_1 = \frac{a}{2}(\hat{j} + \hat{k}); \hat{a}_2 = \frac{a}{2}(\hat{i} + \hat{k}); \hat{a}_3 = \frac{a}{2}(\hat{i} + \hat{j})$$

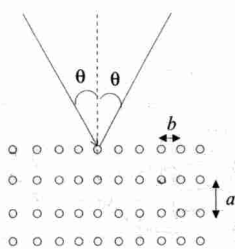
48. The primitive translation vectors of the fcc reciprocal lattice are
(a) $\hat{b}_1 = \left(\frac{2\pi}{a}\right)(-\hat{i} + \hat{j} + \hat{k}); \hat{b}_2 = \left(\frac{2\pi}{a}\right)(\hat{i} - \hat{j} + \hat{k}); \hat{b}_3 = \left(\frac{2\pi}{a}\right)(\hat{i} + \hat{j} - \hat{k})$
(b) $\hat{b}_1 = \left(\frac{\pi}{a}\right)(-\hat{i} + \hat{j} + \hat{k}); \hat{b}_2 = \left(\frac{\pi}{a}\right)(\hat{i} - \hat{j} + \hat{k}); \hat{b}_3 = \left(\frac{\pi}{a}\right)(\hat{i} + \hat{j} - \hat{k})$
(c) $\hat{b}_1 = \left(\frac{\pi}{2a}\right)(-\hat{i} + \hat{j} + \hat{k}); \hat{b}_2 = \left(\frac{\pi}{2a}\right)(\hat{i} - \hat{j} + \hat{k}); \hat{b}_3 = \left(\frac{\pi}{2a}\right)(\hat{i} + \hat{j} - \hat{k})$
(d) $\hat{b}_1 = \left(\frac{3\pi}{a}\right)(-\hat{i} + \hat{j} + \hat{k}); \hat{b}_2 = \left(\frac{3\pi}{a}\right)(\hat{i} - \hat{j} + \hat{k}); \hat{b}_3 = \left(\frac{3\pi}{a}\right)(\hat{i} + \hat{j} - \hat{k})$



49. The volume of the primitive cell of the fcc reciprocal lattice is:
- (a) $4\left(\frac{2\pi}{a}\right)^3$ (b) $4\left(\frac{\pi}{a}\right)^3$ (c) $4\left(\frac{\pi}{2a}\right)^3$ (d) $4\left(\frac{3\pi}{a}\right)^3$
50. A narrow beam of X-rays with wavelength $1.5\text{\AA}$ is reflected from an ionic crystal with an fcc lattice structure with a density of 3.32 g cm^{-3} . The molecular weight is 108 AMU ($1\text{ AMU} = 1.66 \times 10^{-24}\text{ g}$).
- A. The lattice constant is:
 (a) $6.00\text{\AA}$ (b) $4.56\text{\AA}$ (c) $4.00\text{\AA}$ (d) $2.56\text{\AA}$
- B. The sine of the angle corresponding to (111) reflection is:
 (a) $\sqrt{3}/4$ (b) $\sqrt{3}/8$ (c) $1/4$ (d) $1/8$
51. The two dimensional lattice of graphene is an arrangement of Carbon atoms forming a honeycomb lattice of lattice spacing a , as shown below. The carbon atoms occupy the vertices.



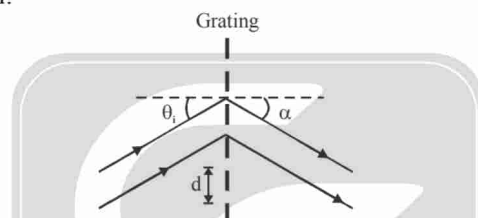
- A. The Wigner-Seitz cell has an area of
 (a) $2a^2$ (b) $\frac{\sqrt{3}}{2}a^2$ (c) $6\sqrt{3}a^2$ (d) $\frac{3\sqrt{3}}{2}a^2$
- B. The Bravais lattice for this array is a
 (a) Rectangular lattice with basis vectors $\bar{d}_1$ and $\bar{d}_2$
 (b) Rectangular lattice with basis vectors $\bar{c}_1$ and $\bar{c}_2$
 (c) Hexagonal lattice with basis vectors $\bar{a}_1$ and $\bar{a}_2$
 (d) Hexagonal lattice with basis vectors $\bar{b}_1$ and $\bar{b}_2$.
52. The co-ordination number of Na^+ and Cl^- in the rock salt structure is respectively
 (a) 8 and 6 (b) 6 and 8 (c) 6 and 6 (d) 4 and 4
53. A monochromatic beam of X-ray with wavelength λ is incident at an angle θ on a crystal with lattice spacing a and b as sketched in the figure below.



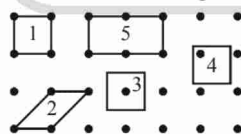
- A condition for there to a maximum in the diffracted X-ray intensity is
 (a) $2\sqrt{a^2 + b^2} \sin \theta = \lambda$ (b) $2b \cos \theta = \lambda$ (c) $2a \cos \theta = \lambda$ (d) $(a + b) \sin \theta = \lambda$
54. Metallic Copper is known to form cubic crystals and the lattice constant is measured from X-ray diffraction studies to be about 0.36 nm . If the specific gravity of Copper is 8.96 and its atomic weight is 63.5, one can conclude that
 (a) the crystals are of simple cubic type (b) the crystals are of b.c.c. type
 (c) the crystals are of f.c.c. type (d) the crystals are a mixture of f.c.c. and b.c.c. types.



55. The experimental method used most frequently for detecting magnetic structure of solids is
 (a) electron diffraction (b) neutron diffraction
 (c) x-ray diffraction (d) photo-emission spectroscopy
56. The most suitable experimental method for studying the dispersion relation of phonons is
 (a) X-ray diffraction (b) elastic scattering of neutrons
 (c) inelastic scattering of thermal neutrons (d) photo-electron emission.
57. A beam of x-rays is incident on a BCC crystal. If the difference between the incident and the scattered wave vectors is $\vec{K} = h\hat{x} + k\hat{y} + l\hat{z}$ where $\hat{x}, \hat{y}, \hat{z}$ are the unit vectors of the associated cubic lattice, the necessary condition for the scattered beam to give a Laue maximum is
 (a) $h + k + l = \text{even}$ (b) $h = k = l$ (c) h, k, l are all distinct (d) $h + k + l = \text{odd}$
58. The second order maximum in the diffraction of X-rays of 0.20 nanometer wavelength from a simple cubic crystal is found to occur at an angle of thirty degrees with respect to the crystal plane. The distance between the lattice planes is
 (a) 1 Angstrom (b) 2 Angstroms (c) 4 Angstroms (d) 8 Angstroms
59. A parallel beam of light of wavelength λ is incident on a transmission grating with groove spacing d , at an angle θ_i , as shown in the figure on the left. The plane of incidence is normal to the grooves. After diffraction, the transmitted beam is seen to be at an angle α relative to the normal. Which of the following conditions must be satisfied for this to happen?



- (a) $d(\sin \theta_i - \sin \alpha) = n\lambda$ (b) $2d \sin(\theta_i - \alpha) = n\lambda$
 (c) $d(\sin \theta_i + \sin \alpha) = n\lambda$ (d) $2d(\alpha + \theta_i) = n\lambda$
60. KCl has the NaCl type structure which is fcc with two-atom basis, one at $(0, 0, 0)$ and the other at $(\frac{1}{2}, \frac{1}{2}, \frac{1}{2})$. Assume that the atomic form factors of K^+ and Cl^- are identical. In an x-ray diffraction experiment on KCl, which of the following $(h k l)$ peaks will be observed?
 (a) $(1 0 0)$ (b) $(1 1 0)$ (c) $(1 1 1)$ (d) $(2 0 0)$
61. For the given unit cells of a two dimensional square lattice, which option lists all the primitive cells?



[GATE 2018]

- (a) 1 and 2 (b) 1, 2 and 3 (c) 1, 2, 3 and 4 (d) 1, 2, 3, 4 and 5
62. Which of the combinations of crystal structure and their coordination number is(are) correct?
 (a) body centered cubic – 8 (b) face centered cubic – 6
 (c) diamond – 4 (d) hexagonal closed packed – 12
63. The lattice constant of unit cell of NaCl crystal is 0.563 nm. X-rays of wavelength 0.141 nm are diffracted by this crystal. The angle at which the first order maximum occurs is _____ degrees. (Specify your answer in degrees upto two digits after the decimal point)



64. A crystal of MnO has NaCl structure. It has a paramagnetic to anti-ferromagnetic transition at 120 K. Below 120 K, the spins within a single [111] plane are parallel but the spins in adjacent [111] planes are anti-parallel. If neutron scattering is used to determine the lattice constants, respectively, d and d' , below and above the transition temperature of MnO then [NET Dec. 2017]

(a) $d = \frac{d'}{2}$ (b) $d = \frac{d'}{\sqrt{2}}$ (c) $d = 2d'$ (d) $d = \sqrt{2}d'$

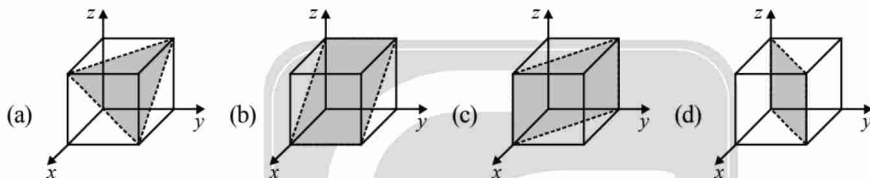
65. Sodium Chloride (NaCl) crystal is a face centred cubic lattice, with a basis consisting of Na^+ and Cl^- ions separated by half the body diagonal of a unit cube. Which of the planes corresponding to the Miller indices given below will not give rise to Bragg reflection of X-rays? [NET June 2018]

(a) (2 2 0) (b) (2 4 2) (c) (2 2 1) (d) (3 1 1)

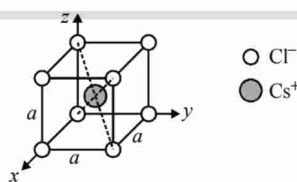
66. Hard discs of radius R are arranged in a two-dimensional triangular lattice. What is the fractional area occupied by the discs in the closest possible packing? [NET June 2018]

(a) $\frac{\pi\sqrt{3}}{6}$ (b) $\frac{\pi}{3\sqrt{2}}$ (c) $\frac{\pi\sqrt{2}}{5}$ (d) $\frac{2\pi}{7}$

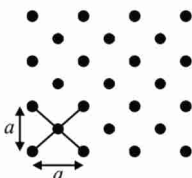
67. Which one of the following crystallographic planes represent (101) Miller indices of a cubic unit cell?



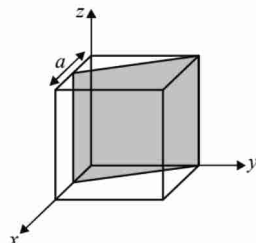
68. The third-nearest neighbour distance in a BCC (Body Centered Cubic) crystal with lattice constant a_0 is [NET June 2019]
 (a) a_0 (b) $3a_0/2$ (c) $\sqrt{3}a_0$ (d) $\sqrt{2}a_0$
69. Sodium (Na) exhibits body-centered-cubic (BCC) crystal structure with atomic radius 0.186 nm. The lattice parameter of Na unit cell is _____ nm. (Round off to 2 decimal places)
70. The crystal structure of CsCl is a simple cubic lattice. Each unit cell of CsCl will contain
 (a) 1 atom (b) 2 atoms (c) 3 atoms (d) 4 atoms
71. The location of Cs^+ and Cl^- ions inside the unit cell of CsCl crystal is shown in the figure. The Bravais lattice of CsCl is



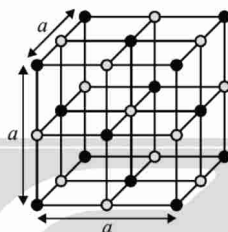
- (a) simple cubic (b) body centered orthorhombic
 (c) face centered cubic (d) basic centered orthorhombic
72. The number of distinct ways the primitive unit cell can be constructed for the two dimensional lattice as shown in the figure is _____. [GATE 2020]



73. The figure below shows a cubic unit cell with lattice constant a . The shaded crystallographic plane intersects the x -axis at $0.5a$. The Miller indices of the shaded plane are



- (a) (210) (b) $(\bar{2}10)$ (c) (110) (d) (102)
74. Consider the crystal structure shown in the figure, where black and grey spheres represent of two different elements and a denotes the lattice constant. The Bravais lattice for this structure is



- (a) Simple cubic (b) Face-centered cubic
(c) Body-centered cubic (d) Triclinic
75. A solid with FCC crystal structure is probed using X-rays of wavelength 0.2 nm. For the crystallographic plane given by (2, 0, 0), a first order diffraction peak is observed for a Bragg angle of 21° . The unit cell size is _____ nm. (Round off to 2 decimal places).

76. A lattice is defined by the unit vectors $\vec{a}_1 = a\hat{i}$, $\vec{a}_2 = -\frac{a}{2}\hat{i} + \frac{a\sqrt{3}}{2}\hat{j}$ and $\vec{a}_3 = a\hat{k}$, where $a > 0$ is a constant. The spacing between the (100) planes of the lattice is

[NET Nov. 2020]

- (a) $\frac{\sqrt{3}a}{2}$ (b) $\frac{a}{2}$ (c) a (d) $\sqrt{2}a$





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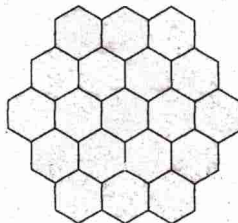
SOLID STATE PHYSICS

Assignment-2

- Atoms, which can be assumed to be hard spheres of radius R , are arranged in an fcc lattice with lattice constant a , such that each atom touches its nearest neighbours. Take the center of one of the atoms as the origin. Another atom of radius r (assumed to be hard sphere) is to be accommodated at a position $(0, a/2, 0)$ without distorting the lattice. The maximum value of r/R is _____. (Give your answer upto two decimal places). [GATE 2016]
- Consider a regular arrangement of identical spheres in a face-centred cubic (fcc) structure in which the centres of the respective spheres are located at each of the eight corners and the centres of the six surfaces of a unit cube. The fraction of each cubic unit cell occupied by the spheres in the close-pack configuration is
(a) 0.50 (b) 0.62 (c) 0.74 (d) 0.88
- The number of different Bravais lattices possible in two dimension is:
(a) 2 (b) 3 (c) 5 (d) 6 [JEST 2016]
- Which of the following statements is correct for NaCl crystal structure?
(a) It is a simple cubic lattice with one atom basis.
(b) It is a face-centered cubic lattice with one atom basis
(c) It is a simple cubic lattice with two atom basis
(d) It is a face-centered cubic lattice with two atom basis.
- The value of θ at which the first-order peak in X-ray ($\lambda = 1.53 \text{ \AA}$) diffraction corresponding to (111) plane of a simple cubic structure with the lattice constant, $a = 2.65 \text{ \AA}$, is approximately
(a) 15° (b) 30° (c) 45° (d) 60°
- The number of second-nearest neighbor ions to a Na^+ ion in NaCl crystal is _____
- The ratio of the second-neighbour distance to the nearest-neighbour distance in an fcc lattice is
(a) $2\sqrt{2}$ (b) 2 (c) $\sqrt{3}$ (d) $\sqrt{2}$
- An X-ray beam of wavelength $1.54 \text{ \AA}$ is diffracted from the (110) planes of a solid with a cubic lattice of lattice constant $3.08 \text{ \AA}$. The first-order Bragg diffraction occurs at
(a) $\sin^{-1}\left(\frac{1}{4}\right)$ (b) $\sin^{-1}\left(\frac{1}{2\sqrt{2}}\right)$ (c) $\sin^{-1}\left(\frac{1}{2}\right)$ (d) $\sin^{-1}\left(\frac{1}{\sqrt{2}}\right)$
- The fraction of volume unoccupied in the unit cell of the body centered cubic lattice is
(a) $\frac{8-\sqrt{3}\pi}{8}$ (b) $\frac{\sqrt{3}\pi}{8}$ (c) $\frac{6-\sqrt{2}\pi}{6}$ (d) $\frac{\pi}{3\sqrt{2}}$
- Diamond lattice can be considered as a combination of two fcc lattices displaced along the body diagonal by one quarter of its length. There are eight atoms per unit cell. The packing fraction of the diamond structure is
(a) 0.48 (b) 0.74 (c) 0.34 (d) 0.68



11. In a single layer of graphite, called graphene, the carbon atoms form a hexagonal lattice (see figure). How many carbon atoms are there in a unit cell of the lattice?



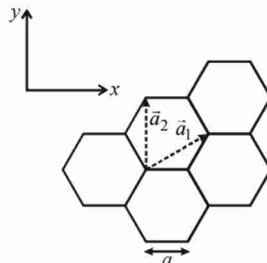
- (a) one (b) two (c) three (d) six
12. An X-ray machine operates at a potential of 5000 V. What is the minimum possible value of wavelength present in the radiations?
(a) 0.0124 nm (b) 0.0245 nm (c) 0.124 nm (d) 0.248 nm
13. Helium atoms at low temperatures make a perfect closed pack structure of hexagonal lattice with parameters $a = 0.36$ nm and $c = 0.59$ nm. The density of the crystal is approximately
(a) 2000 kg/m³ (b) 100 kg/m³ (c) 123 kg/m³ (d) 200 kg/m³
14. Monochromatic X rays of wavelength $1\text{ \AA}$ are incident on a simple cubic crystal. The first order Bragg reflection from (311) plane occurs at an angle of 30° from the plane. The lattice parameter of the crystal in $\text{\AA}$ is:
(a) 1 (b) $\sqrt{3}$ (c) $\sqrt{\frac{11}{2}}$ (d) $\sqrt{11}$
15. The second order maximum in the diffraction of X-rays of 0.20 nanometer wavelength from a simple cubic crystal is found to occur at an angle of thirty degrees with respect to the crystal plane. The distance between the lattice planes is
(a) 1 Angstrom (b) 2 Angstroms (c) 4 Angstroms (d) 8 Angstroms
16. A lattice is characterized by the following primitive vectors (in angstroms) :
 $\vec{a} = 2(\hat{i} + \hat{j})$, $\vec{b} = 2(\hat{j} + \hat{k})$, $\vec{c} = 2(\hat{k} + \hat{i})$. The reciprocal lattice corresponding to the above is:
(a) body centered cubic lattice with cube edge $\pi\text{ \AA}^{-1}$
(b) body centered cubic lattice with cube edge $2\pi\text{ \AA}^{-1}$
(c) face centered cubic lattice with cube edge $\pi\text{ \AA}^{-1}$
(d) face centered cubic lattice with cube edge $2\pi\text{ \AA}^{-1}$
17. A lattice has the following primitive vectors (in A): $\vec{a} = 2(\hat{j} + \hat{k})$, $\vec{b} = 2(\hat{k} + \hat{i})$, $\vec{c} = 2(\hat{i} + \hat{j})$. The reciprocal lattice corresponding to the above lattice is
(a) BCC lattice with cube edge of $\left(\frac{\pi}{2}\right)A^{-1}$ (b) BCC lattice with cube edge of $(2\pi)A^{-1}$
(c) FCC lattice with cube edge of $\left(\frac{\pi}{2}\right)A^{-1}$ (d) FCC lattice with cube edge of $(2\pi)A^{-1}$
(e) none of these



18. The primitive translation vectors of the body centered cubic lattice are $\vec{a} = \frac{a}{2}(\hat{x} + \hat{y} - \hat{z})$, $\vec{b} = \frac{a}{2}(\hat{x} + \hat{y} + \hat{z})$, and $\vec{c} = \frac{a}{2}(\hat{x} - \hat{y} + \hat{z})$. The primitive translation vectors $\vec{A}, \vec{B}$ and $\vec{C}$ of the reciprocal lattice are:
- (a) $\vec{A} = \frac{2\pi}{a}(\hat{x} - \hat{y})$; $\vec{B} = \frac{2\pi}{a}(\hat{y} + \hat{z})$; $\vec{C} = \frac{2\pi}{a}(\hat{x} + \hat{z})$
 (b) $\vec{A} = \frac{2\pi}{a}(\hat{x} + \hat{y})$; $\vec{B} = \frac{2\pi}{a}(\hat{y} - \hat{z})$; $\vec{C} = \frac{2\pi}{a}(\hat{x} + \hat{z})$
 (c) $\vec{A} = \frac{2\pi}{a}(\hat{x} + \hat{y})$; $\vec{B} = \frac{2\pi}{a}(\hat{y} + \hat{z})$; $\vec{C} = \frac{2\pi}{a}(\hat{x} - \hat{z})$
 (d) $\vec{A} = \frac{2\pi}{a}(\hat{x} + \hat{y})$; $\vec{B} = \frac{2\pi}{a}(\hat{y} + \hat{z})$; $\vec{C} = \frac{2\pi}{a}(\hat{x} + \hat{z})$
19. Neutrons moving with speed 10^3 m/s are used for the determination of crystal structure. If the Bragg angle for the first order diffraction is 30° , the interplanar spacing of the crystal is _____ Å.
 (Given: $m_n = 1.675 \times 10^{-27}$ kg, $h = 6.626 \times 10^{-34}$ J.s)
20. If $\vec{k}$ is the wavefactor of incident light ($|\vec{k}| = 2\pi/\lambda$, λ is the wavelength of light) and $\vec{G}$ is a reciprocal lattice vector, then the Bragg's law can be written as: [JEST 2016]
 (a) $\vec{k} + \vec{G} = 0$ (b) $2\vec{k} \cdot \vec{G} + G^2 = 0$ (c) $2\vec{k} \cdot \vec{G} + k^2 = 0$ (d) $\vec{k} \cdot \vec{G} = 0$
21. The reciprocal lattice of an hexagonal crystal is
 (a) fcc (b) bcc (c) hexagonal (d) orthorhombic
22. The structure factor of a single cell of identical atoms of form factor f is given by $Shkl = f \sum_i \exp(-i2\pi(x_j h + y_j k + z_j l))$ where (x_j, y_j, z_j) is the coordinate of an atom, and hkl are the Miller indices. Which one of the following statement is correct for the diffraction peaks of body centered cubic (BCC) and face centered cubic (FCC) lattices?
 (a) BCC : (200); (110); (222) (b) BCC : (210); (110); (222)
 FCC : (111); (311); (400) FCC : (111); (311); (400)
 (c) BCC : (200); (110); (222) (d) BCC : (200); (210); (222)
 FCC : (111); (211); (400) FCC : (111); (211); (400)
23. Which one of the following diffraction peaks will be absent in a powder diffraction pattern for BCC-crystalline powder such as Fe
 (a) (110) (b) (111) (c) (200) (d) (211)
24. Which one of the following axes of rotational symmetry is NOT permissible in single crystals?
 (a) two fold axis (b) three-fold axis (c) four-fold axis (d) five-fold axis
- Common Data for Q. 25 and Q. 26.**
 A crystal belongs to a face centered cubic lattice with four atoms in the unit cell. The size of the crystal is 1 cm and its unit cell dimension is 1 nm. f is the scattering factor of the atom.
25. The number of atoms in the crystal is:
 (a) 2×10^{21} (b) 4×10^{21} (c) 2×10^{23} (d) 4×10^{24}
26. The structure factors for (0 1 0) and (2 0 0) reflections respectively are:
 (a) $2f$ and zero (b) zero and $4f$ (c) $2f$ and $2f$ (d) zero and zero



27. The total number of Na^+ and Cl^- ions per unit cell of NaCl is, [JEST 2015]
 (a) 2 (b) 4 (c) 6 (d) 8
28. Consider a hexagonal lattice with basis vectors as shown in the figure below. [NET Dec. 2016]



If the lattice spacing is $a = 1$, the reciprocal lattice vectors are

- (a) $\left(\frac{4\pi}{3}, 0\right), \left(-\frac{2\pi}{3}, \frac{2\pi}{\sqrt{3}}\right)$ (b) $\left(\frac{4\pi}{3}, 0\right), \left(\frac{2\pi}{3}, \frac{2\pi}{\sqrt{3}}\right)$
 (c) $\left(0, \frac{4\pi}{\sqrt{3}}\right), \left(\pi, \frac{2\pi}{\sqrt{3}}\right)$ (d) $\left(\frac{2\pi}{3}, \frac{2\pi}{\sqrt{3}}\right), \left(-2\pi, \frac{2\pi}{\sqrt{3}}\right)$
29. The real space primitive lattice vectors are $\vec{a}_1 = a\hat{x}$ and $\vec{a}_2 = \frac{a}{2}(\hat{x} + \sqrt{3}\hat{y})$. The reciprocal space unit vectors $\vec{b}_1$ and $\vec{b}_2$ for this lattice are, respectively [GATE 2017]
 (a) $\frac{2\pi}{a}\left(\hat{x} - \frac{\hat{y}}{\sqrt{3}}\right)$ and $\frac{4\pi}{a\sqrt{3}}\hat{y}$ (b) $\frac{2\pi}{a}\left(\hat{x} + \frac{\hat{y}}{\sqrt{3}}\right)$ and $\frac{4\pi}{a\sqrt{3}}\hat{y}$
 (c) $\frac{2\pi}{a\sqrt{3}}\hat{x}$ and $\frac{4\pi}{a}\left(\frac{\hat{x}}{\sqrt{3}} + \hat{y}\right)$ (d) $\frac{2\pi}{a\sqrt{3}}\hat{x}$ and $\frac{4\pi}{a}\left(\frac{\hat{x}}{\sqrt{3}} - \hat{y}\right)$
30. Which of the following bonds has more directional:
 (a) Ionic bonds (b) Covalent (c) Metallic (d) Vander Waals
31. The basis vectors of a two-dimensional Bravais lattice are $\vec{e}_1 = \frac{1}{2}\hat{i} + \frac{\sqrt{3}}{2}\hat{j}$ and $\vec{e}_2 = \frac{1}{2}\hat{i} - \frac{\sqrt{3}}{2}\hat{j}$. A choice of basis vectors for the reciprocal lattice can be [NET Dec. 2019]
 (a) $\frac{4\pi}{\sqrt{3}}\left(\frac{1}{2}\hat{i} - \frac{\sqrt{3}}{2}\hat{j}\right)$ and $\frac{4\pi}{\sqrt{3}}\left(\frac{1}{2}\hat{i} + \frac{\sqrt{3}}{2}\hat{j}\right)$ (b) $\frac{4\pi}{\sqrt{3}}\left(\frac{\sqrt{3}}{2}\hat{i} + \frac{1}{2}\hat{j}\right)$ and $\frac{4\pi}{\sqrt{3}}\left(\frac{\sqrt{3}}{2}\hat{i} - \frac{1}{2}\hat{j}\right)$
 (c) $2\pi\left(\frac{1}{2}\hat{i} + \frac{\sqrt{3}}{2}\hat{j}\right)$ and $2\pi\left(\frac{1}{2}\hat{i} - \frac{\sqrt{3}}{2}\hat{j}\right)$ (d) $2\pi\left(\frac{\sqrt{3}}{2}\hat{i} + \frac{1}{2}\hat{j}\right)$ and $2\pi\left(\frac{\sqrt{3}}{2}\hat{i} - \frac{1}{2}\hat{j}\right)$
32. Graphite, an allotrope of carbon, crystallizes in a simple hexagonal crystal structure with primitive translation vectors of the hexagonal space lattice given by

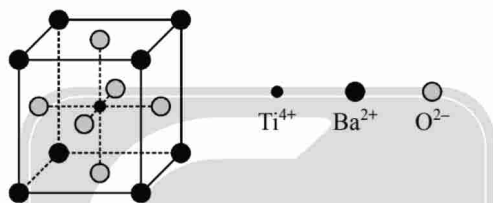
$$\mathbf{a}_1 = \frac{\sqrt{3}}{2}a\hat{x} + \frac{a}{2}\hat{y} ; \mathbf{a}_2 = -\frac{\sqrt{3}}{2}a\hat{x} + \frac{a}{2}\hat{y} ; \mathbf{a}_3 = c\hat{z}$$

Here $a = 2.46 \text{ \AA}$ and $c = 6.7 \text{ \AA}$. Given that there is one atom in the primitive cell, the density of graphite is given by (Take the mass number of carbon to be 12)

- (a) 0.56 gm/cm^3 (b) 5.10 gm/cm^3 (c) 2.40 gm/cm^3
 (d) 1.40 gm/cm^3 (e) 4.32 gm/cm^3



33. Let $\vec{a}_1 = \hat{x}$ and $\vec{a}_2 = \frac{(\sqrt{3}\hat{x} + \hat{y})}{2}$ be the primitive vectors of a two-dimensional lattice, where $\hat{x}$ and $\hat{y}$ are orthogonal unit vectors. If one of the corresponding reciprocal vectors is $\vec{b}_2 = 4\pi\hat{y}$, then the other one is
- (a) $\vec{b}_1 = 2\pi(\hat{x} + \sqrt{3}\hat{y})$ (b) $\vec{b}_1 = 2\pi(-\hat{x} + \sqrt{3}\hat{y})$
 (c) $\vec{b}_1 = 2\pi\hat{x}$ (d) $\vec{b}_1 = 2\pi(\hat{x} - \sqrt{3}\hat{y})$ (e) $\vec{b}_1 = 2\pi\sqrt{3}\hat{y}$
34. If there are n -atoms in the primitive cell, the phonon dispersion relation had optical branches:-
 (a) $3n - 3$ (b) $3n - 2$ (c) $3n - 1$ (d) none
35. Barium Titanate (BaTiO_3) crystal has a cubic perovskite structure, where the Ba^{2+} ions are at the vertices of a unit cube, the O^{2-} ions are at the centres of the faces while the Ti^{4+} is at the centre. The number of optical phonon modes of the crystal is [NET Dec. 2018]



- (a) 12 (b) 15 (c) 5 (d) 18
36. The origin of van der Waals interaction of molecular crystals is:
 (a) nuclear (b) magnetic (c) ionic (d) fluctuating dipolar
37. In a cubic crystal, atoms of mass M_1 lie on one set of planes and atoms of mass M_2 lie on planes interleaved between those of the first set. If C is the force constant between nearest neighbour planes, the frequency of lattice vibrations for the optical phonon branch with wavevector $k = 0$ is:
 (a) $\sqrt{2C\left(\frac{1}{M_1} + \frac{1}{M_2}\right)}$ (b) $\sqrt{C\left(\frac{1}{M_1} + \frac{1}{M_2}\right)}$ (c) $\sqrt{C\left(\frac{1}{M_1} + \frac{1}{2M_2}\right)}$ (d) 0
38. A compound formed by elements A and B crystallizes in cubic structure, in which atoms of A are at the corners while that of B are at the face center. The formula of the compound is
 (a) AB_3 (b) AB (c) AB_6 (d) A_2B
39. A typical semiconductor such as Ge is formed by what kind of bonds?
 (a) Covalent (b) Ionic (c) van der Waals (d) Metallic
40. The free energy difference between the superconducting and the normal states of a material is given by $\Delta F = F_S - F_N = \alpha|\psi|^2 + \frac{\beta}{2}|\psi|^4$, where ψ is an order parameter and α and β are constants such that $\alpha > 0$ in the normal and $\alpha < 0$ in the superconducting state, while $\beta > 0$ always. The minimum value of ΔF in the superconducting state is
 (a) $-\alpha^2 / \beta$ (b) $-\alpha^2 / 2\beta$ (c) $-3\alpha^2 / 2\beta$ (d) $-5\alpha^2 / 2\beta$

41. The solid phase of an element follows van der Waals bonding with inter-atomic potential $V(r) = -\frac{P}{r^6} + \frac{Q}{r^{12}}$, where P and Q are constants. The bond length can be expressed as
- (a) $\left(\frac{2Q}{P}\right)^{1/6}$ (b) $\left(\frac{Q}{P}\right)^{-6}$ (c) $\left(\frac{P}{2Q}\right)^{-6}$ (d) $\left(\frac{P}{Q}\right)^{-6}$
42. The total energy of an inert-gas crystal is given by $E(R) = \frac{0.5}{R^{12}} - \frac{1}{R^6}$ (in eV), where R is the inter-atomic spacing in Angstroms. The equilibrium separation between the atoms is _____ Angstroms. (up to two decimal places). [GATE 2017]
43. The total energy of an ionic solid is given by an expression $E = -\frac{\alpha e^2}{4\pi\epsilon_0 r} + \frac{B}{r^9}$ where α is Madelung constant, r is the distance between the nearest neighbours in the crystal and B is a constant. If r_0 is the equilibrium separation between the nearest neighbours then the value of B is
- (a) $\frac{\alpha e^2 r_0^8}{36\pi\epsilon_0}$ (b) $\frac{\alpha e^2 r_0^8}{4\pi\epsilon_0}$ (c) $\frac{2\alpha e^2 r_0^{10}}{9\pi\epsilon_0}$ (d) $\frac{\alpha e^2 r_0^{10}}{36\pi\epsilon_0}$
44. Consider a three-dimensional crystal of N inert gas atoms. The total energy is given by
- $$U(R) = 2N\epsilon \left[p \left(\frac{\sigma}{R} \right)^{12} - q \left(\frac{\sigma}{R} \right)^6 \right],$$
- where $p = 12.13$, $q = 14.45$, and R is the nearest neighbour distance between two atoms. The two constants, ϵ and R , have the dimensions of energy and length, respectively. The equilibrium separation between two nearest neighbour atoms in units of σ (rounded off to two decimal places) is _____. [GATE 2019]
45. The binding energy per molecule of NaCl (lattice parameter is 0.563 nm) is 7.95 eV. The repulsive term of the potential is of the form $\frac{K}{r^9}$, where K is a constant. The value of Madelung constant is _____ (upto three decimal places). [GATE 2015]
- (Electron charge $e = -1.6 \times 10^{-19}$ C; $\epsilon_0 = 8.854 \times 10^{-12}$ C²N⁻¹m⁻²).
46. The energy of a ferromagnet as a function of magnetization M is given by:
 $F(M) = F_0 + 2(T - T_c) M^2 + M^4$, $F_0 > 0$
 The number of minima in the function $F(M)$ for $T > T_c$ is:
 (a) 0 (b) 1 (c) 3 (d) 4
47. At low temperature the specific heat of insulating crystals varies as:
 (a) AT^3 (b) $BT + CT^3$
 (c) $D \exp(E/T)$ (d) will not change with temperature
48. A cubic cell consists of two atoms of masses m_1 and m_2 ($m_1 > m_2$) with m_1 and m_2 atoms situated on alternate planes. Assuming only nearest neighbour interactions, the center of mass of the two atoms:
 (a) moves with the atoms in the optical mode and remains fixed in the acoustic mode
 (b) remains fixed in the optical mode and moves with the atoms in the acoustic mode
 (c) remains fixed in both optical and acoustic modes
 (d) moves with the atoms in both optical and acoustic modes



49. A linear diatomic lattice of lattice constant a with masses M and m ($M > m$) are coupled by a force constant C . The dispersion relation is given by:

$$\omega_{\pm}^2 = C \left(\frac{M+m}{Mm} \right) \pm \left[C^2 \left(\frac{M+m}{M} \right)^2 - \frac{4C^2}{Mm} \sin^2 \frac{ka}{2} \right]^{1/2}$$

Which one of the following statements is incorrect?

- (a) The atoms vibrating in transverse mode correspond to the optical branch
 (b) The maximum frequency of the acoustic branch depends on the mass of the lighter atom.
 (c) The dispersion of frequency in the optical branch is smaller than that in the acoustic branch.
 (d) No normal modes exist in the acoustic branch for any frequency greater than the maximum frequency at $k = \frac{\pi}{a}$.

50. The potential of a diatomic molecule as a function of the distance r between the atoms is given by

$$V(r) = -\frac{a}{r^6} + \frac{b}{r^{12}}. \text{ The value of the potential at equilibrium separation between the atoms is :}$$

- (a) $-4a^2/b$ (b) $-2a^2/b$ (c) $-a^2/2b$ (d) $-a^2/4b$
51. At the equilibrium spacing of a diatomic molecule, the resultant force is
 (a) zero (b) minimum (c) maximum (d) unity
52. The potential energy in the above said spacing is
 (a) zero (b) minimum (c) maximum (d) unity
53. Which of the interatomic bonds are directional?
 (a) covalent (b) metallic (c) ionic (d) van der Waals
54. The number of phonon branch in graphite, with four atoms in the primitive cell, is
 (a) 8, out of which two are acoustic, the rest optical
 (b) 9, out of which three are acoustic, the rest optical
 (c) 12, out of which three are acoustic, the rest optical
 (d) 12, out of which two are acoustic, the rest optical
55. The excitation of a three-dimensional solid are bosonic in nature with their frequency ω and wave-number k are related by $\omega \propto k^2$ in the large wavelength limit. If the chemical potential is zero, the behaviour of the specific heat of the system at low temperature is proportional to
 (a) $T^{1/2}$ (b) T (c) $T^{3/2}$ (d) T^3
56. In the Debye model of the specific heat of solids, which of the following holds true?
 (a) The phonon frequencies are treated as independent of the wave vector and the low temperature specific heat behaves as $C_v \propto T^3$.
 (b) Electron-electron repulsion is the key ingredient and the low temperature specific heat behaves as $C_v \propto T$.
 (c) The phonon frequencies are taken to have the sound wave like dispersion and the low temperature specific heat behaves as $C_v \propto T^3$.
 (d) The specific heat due to lattice vibrations is temperature independent.
 (e) The phonon frequencies are treated as independent of the wave vector and the low temperature specific heat behaves as $C_v \propto T^3$.
57. The nature of the interaction that gives rise to the van der Waals force in a molecular crystal is
 (a) dipolar (b) nuclear (c) magnetic (d) quadrupolar



58. The specific heat of a normal metal at low temperatures is dominated by the contribution of
 (a) conduction electrons (b) acoustic phonons
 (c) core electrons (d) optical phonons
59. According to the Debye model, the internal energy of a solid at temperature T close to absolute zero varies as
 (a) T^2 (b) T^4 (c) T^3 (d) T
60. At low temperature, the measured specific heat C_V of a sample is found to depend on temperature as $C_V = aT^{3/2} + bT^3$, where a and b are constants. This material has
 (a) one fermionic excitation with dispersion relation $\omega \propto k^4$;
 another bosonic excitation with dispersion relation $\omega \propto k$ [TIFR 2019]
 (b) one fermionic excitation with dispersion relation $\omega \propto k^2$;
 another fermionic excitation with dispersion relation $\omega \propto k$
 (c) one fermionic excitation with dispersion relation $\omega \propto k^2$;
 another bosonic excitation with dispersion relation $\omega \propto k^4$
 (d) one bosonic excitation with dispersion relation $\omega \propto k^2$;
 another bosonic excitation with dispersion relation $\omega \propto k$
61. At low temperatures, in the Debye approximation, the contribution of the phonons to the heat capacity of a two-dimensional solid is proportional to [CSIR-NET Dec. 2018]
 (a) T^2 (b) T^3 (c) $T^{1/2}$ (d) $T^{3/2}$
62. In order to estimate the specific heat of phonons, the appropriate method to apply would be
 (a) Einstein model for acoustic phonons and Debye model for optical phonons. [GATE 2019]
 (b) Einstein model for optical phonons and Debye model for acoustic phonons.
 (c) Einstein model for both optical and acoustic phonons.
 (d) Debye model for both and acoustic phonons.
63. In the continuum model of an elastic solid, the frequency of sound waves
 (a) is constant in some directions and proportional to the wave-vector in other directions
 (b) is proportional to the square of the wave-vector
 (c) is a constant independent of the wave-vector
 (d) is proportional to the wave-vector in all directions.
64. The number of acoustic phonon branches in a three-dimensional crystal with 3 atoms per primitive cell is
 (a) 6 (b) 9 (c) 3 (d) 12
65. The dispersion relation of optical phonons in a cubic crystal is given by $\omega(k) = \omega_0 - ak^2$, where ω_0 and a are positive constants. The contribution to the density of states due to these phonons with frequencies just below ω_0 is proportional to [NET Dec. 2018]
 (a) $(\omega_0 - \omega)^{1/2}$ (b) $(\omega_0 - \omega)^{3/2}$ (c) $(\omega_0 - \omega)^2$ (d) $(\omega_0 - \omega)$
66. Suppose the frequency of phonons in a one-dimensional chain of atoms is proportional to the wavevector. If n is the number density of atoms and c is the speed of the phonons, then the Debye frequency is
 (a) $2\pi cn$ (b) $\sqrt{2}\pi cn$ (c) $\sqrt{3}\pi cn$ (d) $\frac{\pi cn}{2}$ [NET June 2016]
67. In the X-ray diffraction pattern recorded for a simple cubic solid (lattice parameter $a = 1 \text{ \AA}$) using X rays of wavelength $1 \text{ \AA}$, the first order diffraction peak(s) would appear for the
 (a) (100) planes (b) (112) planes (c) (210) planes (d) (220) planes



68. Consider a two dimensional crystal with 3 atoms in the basis. The number of allowed optical branches (n) and acoustic branches (m) due to the lattice vibrations are [GATE 2020]
 (a) $(n, m) = (3, 3)$ (b) $(n, m) = (2, 4)$ (c) $(n, m) = (4, 2)$ (d) $(n, m) = (1, 5)$
69. Consider a simple cubic monoatomic Bravais lattice which has a basis with vectors $\vec{r}_1 = 0$, $\vec{r}_2 = \frac{a}{4}(\hat{x} + \hat{y} + \hat{z})$, a is the lattice parameter. The Bragg reflection is observed due to the change in the wave vector between the incident and the scattered beam as given by $\vec{K} = n_1 \vec{G}_1 + n_2 \vec{G}_2 + n_3 \vec{G}_3$, where $\vec{G}_1$, $\vec{G}_2$ and $\vec{G}_3$ are primitive reciprocal lattice vectors. For $n_1 = 3$, $n_2 = 3$ and $n_3 = 2$ the geometrical structure factor is _____.

[GATE 2020]





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SOLID STATE PHYSICS

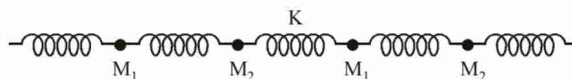
Assignment-3

1. Which one of the following CANNOT be explained by considering a harmonic approximation for the lattice vibrations in solids ?
- (a) Debye's T^3 law (b) Dulong petit's law
(c) Optical branches in lattices (d) Thermal expansion

Common data for Q. 2 and Q. 3

The dispersion relation for a one dimensional monatomic crystal with lattice spacing a , which interacts via nearest neighbour harmonic potential is given by $\omega = A \left| \sin \frac{Ka}{2} \right|$, where A is a constant of appropriate unit.

2. The group velocity at the boundary of the first Brillouin zone is
- (a) 0 (b) 1 (c) $\sqrt{\frac{Aa^2}{2}}$ (d) $\frac{1}{2} \sqrt{\frac{Aa^2}{2}}$
3. The force constant between the nearest neighbour of the lattice is (M is the mass of the atom)
- (a) $\frac{MA^2}{4}$ (b) $\frac{MA^2}{2}$ (c) MA^2 (d) $2MA^2$
4. The Dulong Petit law fails near room temperature (300 K) for many light elements (such as boron and beryllium) because their Debye temperature is
- (a) $\gg 300$ K (b) ~ 300 K (c) $\ll 300$ K (d) 0 K
5. The dispersion relation of phonons in a solid is given by $\omega^2(k) = \omega_0^2 (3 - \cos k_x a - \cos k_y a - \cos k_z a)$
- The velocity of the phonons at large wavelength is
- (a) $\omega_0 a / \sqrt{3}$ (b) $\omega_0 a$ (c) $\sqrt{3} \omega_0 a$ (d) $\omega_0 a / \sqrt{2}$
6. The phonon dispersion for the following one-dimensional diatomic lattice with masses M_1 and M_2 (as shown in the figure)



is given by

$$\omega^2(q) = K \left(\frac{1}{M_1} + \frac{1}{M_2} \right) \left[1 \pm \sqrt{1 - \frac{4M_1M_2}{(M_1 + M_2)^2} \sin^2 \left(\frac{qa}{2} \right)} \right]$$

where a is the lattice parameter and K is spring constant. The velocity of sound is

- (a) $\sqrt{\frac{K(M_1 + M_2)}{2M_1M_2}} a$ (b) $\sqrt{\frac{K}{2(M_1 + M_2)}} a$ (c) $\sqrt{\frac{K(M_1 + M_2)}{M_1M_2}} a$ (d) $\sqrt{\frac{KM_1M_2}{2(M_1 + M_2)^3}} a$

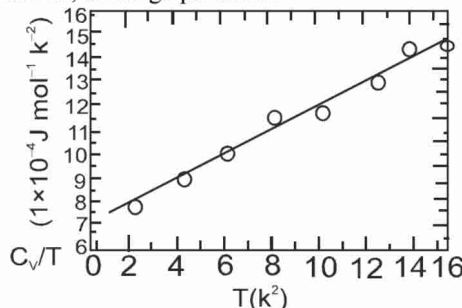


7. For crystals, having two atoms per primitive cell, square of angular frequency of lattice vibration is given by $\omega^2 = \frac{C/2}{M_1 + M_2} K^2 a^2$ corresponds to
- (a) Optical branch (b) Acoustical branch
(c) To both acoustical and optical branches (d) Band gap
8. Using the frequency-dependent Drude formula, what is the effective kinetic inductance of a metallic wire that is to be used as a transmission line? [In the following, the electron mass is m , density of electrons is n , and the length and cross-sectional area of the wire are ℓ and A respectively]
- (a) $mA / (ne^2 \ell)$ (b) zero (c) $m\ell / (ne^2 A)$ (d) $m\sqrt{A} / (ne^2 \ell^2)$
9. The lattice specific heat C of a crystalline solid can be obtained using the Dulong Petit model, Einstein model and Debye model. At low temperature $\hbar\omega \gg K_B T$, which one of the following statements is true (a and A are constants)
- (a) Dulong Petit: $C \propto \exp\left(\frac{-a}{T}\right)$; Einstein: $C = \text{constant}$, Debye: $C \propto \left(\frac{T}{A}\right)^3$
(b) Dulong Petit: $C = \text{constant}$; Einstein: $C \propto \left(\frac{T}{A}\right)^3$; Debye: $C \propto \exp\left(\frac{-a}{T}\right)$
(c) Dulong Petit: $C = \text{constant}$; Einstein: $C \propto \frac{e^{-a/T}}{T^2}$; Debye: $C \propto \left(\frac{T}{A}\right)^3$
(d) Dulong Petit: $C \propto \left(\frac{T}{A}\right)^3$; Einstein: $C \propto \frac{e^{-a/T}}{T^2}$; Debye: $C = \text{constant}$
10. A uniform linear monoatomic chain is modeled by a spring-mass system of masses m separated by nearest neighbor distance a and spring constant $m\omega_0^2$. The dispersion relation for this system is
- (a) $\omega(k) = 2\omega_0 \left(1 - \cos\left(\frac{ka}{2}\right)\right)$ (b) $\omega(k) = 2\omega_0 \sin^2\left(\frac{ka}{2}\right)$
(c) $\omega(k) = 2\omega_0 \sin\left(\frac{ka}{2}\right)$ (d) $\omega(k) = 2\omega_0 \tan\left(\frac{ka}{2}\right)$
11. Debye temperatures of copper and gold are 340K and 170K, respectively. At room temperature, if the specific heat for copper is $1.5 \text{ kJmol}^{-1}\text{K}^{-1}$, the specific heat for gold is about:
- (a) $0.19 \text{ kJmol}^{-1}\text{K}^{-1}$ (b) $1.2 \text{ kJmol}^{-1}\text{K}^{-1}$ (c) $1.9 \text{ kJmol}^{-1}\text{K}^{-1}$ (d) $12 \text{ kJmol}^{-1}\text{K}^{-1}$
12. Consider two crystalline solids, one of which has a simple cubic structure, and the other has a tetragonal structure. The effective spring constant between atoms in the c -direction is half the effective spring constant between atoms in the a and b directions. At low temperatures, the behaviour of the lattice contribution to the specific heat will depend as a function of temperature T as
- (a) T^2 for the tetragonal solid, but as T^3 for the simple cubic solid
(b) T for the tetragonal solid and as T^3 for the simple cubic solid
(c) T for both solids (d) T^3 for both solids
13. A one-dimensional linear chain of atoms contains two types of atoms of masses m_1 and m_2 (where $m_2 > m_1$), arranged alternately. The distance between successive atoms is the same. Assume that the harmonic approximation is valid. At the first Brillouin zone boundary, which of the following statements is correct?
- (a) The atoms of mass m_2 are at rest in the optical mode, while they vibrate in the acoustical mode.
(b) The atoms of mass m_1 are at rest in the optical mode, while they vibrate in the acoustical mode.
(c) Both types of atoms vibrate with equal amplitudes in the optical as well as in the acoustical modes.
(d) Both types of atoms vibrate, but with unequal, non-zero amplitudes in the optical as well as in the acoustical modes.

[GATE 2016]



14. The dispersion relation for phonons in a one dimensional monatomic Bravais lattice with lattice spacing a and consisting of ions of masses M is given by, $\omega(k) = \sqrt{\frac{2C}{M}[1 - \cos(ka)]}$, where ω is the frequency of oscillation, k is the wavevector and C is the spring constant. For the long wavelength modes ($\lambda \gg a$), the ratio of the phase velocity to the group velocity is _____ [GATE 2015]
15. The ratio of the specific heat capacity and temperature, C_v / T , of Cu is plotted as a function of T^2 , the square of the absolute temperature, in the graph below:



- The values of γ and β (the coefficients corresponding to the electronic and the vibrational components of the specific heat) are, approximately
- (a) $\gamma = 7.0 \times 10^{-4} \text{ J mol}^{-1} \text{ K}^{-2}$ and $\beta = 5.0 \times 10^{-5} \text{ J mol}^{-1} \text{ K}^{-4}$
- (b) $\gamma = 5.0 \times 10^{-5} \text{ J mol}^{-1} \text{ K}^{-2}$ and $\beta = 7.0 \times 10^{-4} \text{ J mol}^{-1} \text{ K}^{-4}$
- (c) $\gamma = 1.4 \times 10^{-3} \text{ J mol}^{-1} \text{ K}^{-2}$ and $\beta = 7.0 \times 10^{-4} \text{ J mol}^{-1} \text{ K}^{-4}$
- (d) $\gamma = 5.0 \times 10^{-4} \text{ J mol}^{-1} \text{ K}^{-2}$ and $\beta = 7.0 \times 10^{-5} \text{ J mol}^{-1} \text{ K}^{-4}$
16. The Fermi energies of two metals X and Y are 5 eV and 7 eV and their Debye temperatures are 170 K and 340 K, respectively. The molar specific heats of these metals at constant volume at low temperatures can be written as $(C_v)_X = \gamma_X T + A_X T^3$ and $(C_v)_Y = \gamma_Y T + A_Y T^3$, where γ and A are constants. Assuming that the thermal effective mass of the electrons in the two metals are same, which of the following is correct? [GATE 2016]
- (a) $\frac{\gamma_X}{\gamma_Y} = \frac{7}{5}, \frac{A_X}{A_Y} = 8$
- (b) $\frac{\gamma_X}{\gamma_Y} = \frac{7}{5}, \frac{A_X}{A_Y} = \frac{1}{8}$
- (c) $\frac{\gamma_X}{\gamma_Y} = \frac{5}{7}, \frac{A_X}{A_Y} = \frac{1}{8}$
- (d) $\frac{\gamma_X}{\gamma_Y} = \frac{5}{7}, \frac{A_X}{A_Y} = 8$
17. Consider the Fermi-Dirac distribution function $f(E)$ at room temperature (300 K) where E refers to energy. If E_F is the Fermi energy, which of the following is true?
- (a) $f(E)$ is a step function
- (b) $f(E_F)$ has a value of $1/2$
- (c) States with $E < E_F$ are filled completely
- (d) $f(E)$ is large and tends to infinity as E decreases much below E_F
18. Consider the energy E in the first Brillouin zone as a function of the magnitude of the wave vector k for a crystal of lattice constant a . Then
- (a) the slope of E versus k is proportional to the group velocity
- (b) the slope of E versus k has its maximum value at $|k| = \pi/a$
- (c) the plot of E versus k will be parabolic in the interval $(-\pi/a) < k < (\pi/a)$
- (d) the slope of E versus k is non-zero for all k in the interval $(-\pi/a) < k < (\pi/a)$

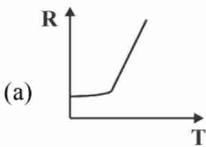
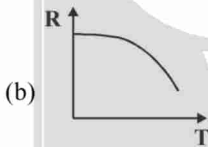
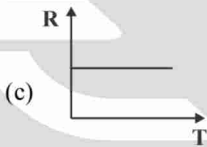
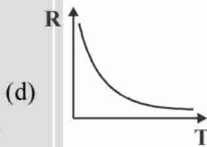


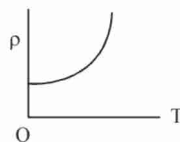
Statement for Linked Answer Q. 19 and Q. 20.

The atomic density of a solid is $5.85 \times 10^{28} \text{ m}^{-3}$. Its electrical resistivity is $1.6 \times 10^{-8} \Omega \text{ m}$. Assume that electrical conduction is described by the Drude model (classical theory), and that each atom contributes one conduction electron.

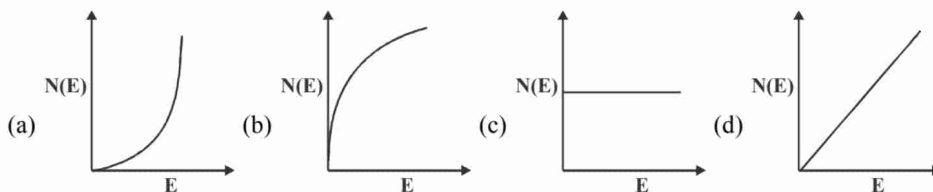
19. The drift mobility (in $\text{m}^2 \text{V}^{-1} \text{s}^{-1}$) of the conduction electrons is:
 (a) 6.67×10^{-3} (b) 6.67×10^{-6} (c) 7.63×10^{-3} (d) 7.63×10^{-6}
20. The relaxation time (mean free time), in seconds, of the conduction electrons is:
 (a) 3.98×10^{-15} (b) 3.79×10^{-14} (c) 2.84×10^{-12} (d) 2.64×10^{-11}
21. Metallic monovalent sodium crystallizes in body centered cubic structure. If the length of the unit cell is $4 \times 10^{-8} \text{ cm}$, the concentration of conduction electrons in metallic sodium is:
 (a) $6.022 \times 10^{23} \text{ cm}^{-3}$ (b) $3.125 \times 10^{22} \text{ cm}^{-3}$ (c) $2.562 \times 10^{21} \text{ cm}^{-3}$ (d) $1.250 \times 10^{20} \text{ cm}^{-3}$
22. The kinetic energy of a free electron at a corner of the first Brillouin zone of a two dimensional square lattice is larger than that of an electron at the mid-point of a side of the zone by a factor b . The value of b is:
 (a) $b = \sqrt{2}$ (b) $b = 2$ (c) $b = 4$ (d) $b = 8$
23. Consider a 2-D square lattice. The ratio of the kinetic energy of a free electron at a corner of the first Brillouin zone (E_c) to that of an electron at the midpoint of a side face of the same zone (E_m) is $E_c/E_m =$
 (a) $1/2$ (b) 2 (c) $\sqrt{2}$ (d) 1 [TIFR 2017]
24. The valence electrons do not directly determine the following property of a metal.
 (a) Electrical conductivity (b) Thermal conductivity
 (c) Shear modulus (d) metallic lustre.
25. For a two-dimensional free electron gas, the electronic density n , and the Fermi energy E_F , are related by
 (a) $n = \frac{(2mE_F)^{3/2}}{3\pi^2\hbar^3}$ (b) $n = \frac{mE_F}{\pi\hbar^2}$ (c) $n = \frac{mE_F}{2\pi\hbar^2}$ (d) $n = \frac{2^{3/2}(mE_F)^{1/2}}{\pi\hbar}$
26. The resistivity of metals:
 (a) Always varies as T^5
 (b) is independent of temperature
 (c) increases linearly with temperature at room temperature and above
 (d) attains a constant value as temperature tends to absolute zero
27. In simple metals the phonon contribution to the electrical resistivity at temperature T is:
 (a) directly proportional to T above Debye temperature and to T^3 below it.
 (b) inversely proportional to T for all temperatures
 (c) independent of T for all temperatures
 (d) directly proportional to T above Debye temperature and to T^5 below it
28. For T much less than the Debye temperature of copper, the temperature dependence of the specific heat at constant volume of copper, is given by (in the following a and b are positive constants)
 (a) aT^3 (b) $aT + bT^3$ (c) $aT^2 + bT^3$ (d) $\exp\left(-\frac{a}{k_B T}\right)$ [NET Dec. 2019]
29. For a Fermi gas of N particles in three dimensions at $T = 0 \text{ K}$, the Fermi energy, E_F
 (a) $N^{2/3}$ (b) $N^{3/2}$ (c) N^3 (d) N^2



30. For an energy state E of a photon gas, the density of states is proportional to:
 (a) $\sqrt{E}$ (b) E (c) $E^{3/2}$ (d) E^2
31. Density of states of free electrons in a solid moving with an energy 0.1 eV is given by $2.15 \times 10^{21} \text{ eV}^{-1} \text{ cm}^{-3}$. The density of states in $\text{eV}^{-1} \text{ cm}^{-3}$ for electrons moving with an energy of 0.4 eV will be:
 (a) 1.07×10^{21} (b) 1.52×10^{21} (c) 3.04×10^{21} (d) 4.30×10^{21}
32. Which one of the statements about density of states is not true?
 (a) Variation in the energy dependence of density of states is dimension independent.
 (b) Variation in the energy dependence of density of states in 3D follows $E^{1/2}$
 (c) Variation in the energy dependence of density of states in 2D follows E^0
 (d) Variation in the energy dependence of density of states in 1D follows $E^{-1/2}$
33. Which one of the following statements is NOT correct about the Brillouin zones (BZ) of a square lattices with constant a ?
 (a) The first BZ is a square of size $2\pi/a$ in k_x - k_y plane
 (b) The areas of the first BZ and third BZ are the same
 (c) The k -points are equidistant in k_x as well as in k_y directions
 (d) The area of the second BZ is twice that of the first BZ
34. An electron confined within a thin layer of semiconductor may be treated as a free particle inside an infinitely deep one-dimensional potential well. If the difference in energies between the first and the second energy levels is δE , then the thickness of the layer is: [JEST 2016]
 (a) $\sqrt{\frac{3\hbar^2\pi^2}{2m\delta E}}$ (b) $\sqrt{\frac{2\hbar^2\pi^2}{3m\delta E}}$ (c) $\sqrt{\frac{\hbar^2\pi^2}{2m\delta E}}$ (d) $\sqrt{\frac{\hbar^2\pi^2}{m\delta E}}$
35. Temperature dependence of resistivity of a metal can be described by
 (a)  (b)  (c)  (d) 
36. A copper wire is 1 metre long and has a uniform cross-section of 0.4 mm^2 . The resistance of the wire at room temperature is 0.171 ohm . What is the resistivity of the material?
 (a) $1.71 \times 10^{-6} \Omega \cdot \text{m}$ (b) $1.71 \times 10^{-7} \Omega \cdot \text{m}$ (c) $1.71 \times 10^{-8} \Omega \cdot \text{m}$ (d) $1.71 \times 10^{-9} \Omega \cdot \text{m}$
37. As the Fermi energy of silver is $8.8 \times 10^{-19} \text{ joule}$, the velocity of the fastest electron in the silver at 0 K . (Given: Rest mass of electron = $9.1 \times 10^{-31} \text{ kg}$) is:
 (a) $3.33 \times 10^5 \text{ m/s}$ (b) $4.40 \times 10^7 \text{ m/s}$ (c) $1.39 \times 10^6 \text{ m/s}$ (d) $3 \times 10^8 \text{ m/s}$
38. The temperature dependence of the electrical resistivity ρ of a material is shown in the plot below. This material is a
 (a) insulator (b) semiconductor (c) normal metal (d) superconductor



39. For Li metal, the resistivity at 77K is $1.01 \mu\Omega - \text{cm}$ and that at 273K is $8.57 \mu\Omega - \text{cm}$. The ratio of the mean collision times, $\frac{\tau_{77}}{\tau_{273}}$ is approximately,
- (a) 3 (b) 1/9 (c) 9 (d) 1/3
40. The real part of the ac conductivity of a metal at a large frequency ω ($\omega\tau \gg 1$, τ = mean collision time).
- (a) increases as ω (b) decreases $\frac{1}{\omega^2}$
 (c) becomes independent of ω (d) varies as $\sqrt{\omega}$
41. For an ideal Fermi gas in three dimensions, the electron velocity V_F at the Fermi surface is related to electron concentration n as,
- (a) $V_F \propto n^{2/3}$ (b) $V_F \propto n$ (c) $V_F \propto n^{1/2}$ (d) $V_F \propto n^{1/3}$
42. The radius of the Fermi sphere of free electrons in a monovalent metal with an fcc structure, in which the volume of the unit cell is a^3 , is
- (a) $\left(\frac{12\pi^2}{a^3}\right)^{1/3}$ (b) $\left(\frac{3\pi^2}{a^3}\right)^{1/3}$ (c) $\left(\frac{\pi^2}{a^3}\right)^{1/3}$ (d) $\frac{1}{a}$
43. The fraction of electrons excited across the energy gap of 0.7 eV in Ge, at room temperature is
- (a) 0 (b) 1.4×10^{-6} (c) 1.6×10^{-8} (d) 1.03×10^{-12}
44. What is the value of potential energy V , in a free electron gas theory of metals?
- (a) A constant (b) Infinite
 (c) It varies with the distance (d) zero
45. Which of the following statement best explains why the specific heat of electrons in metals is much smaller than that expected in a non-interacting (free) electron gas model?
- (a) The mass of electron is much smaller than that of the ions in the crystal.
 (b) The Pauli exclusion principle restricts the number of electrons which can absorb thermal energy
 (c) Electron spin can take only two different values.
 (d) Electrons in a metal cannot be modelled as non-interacting.
46. For a free electron gas in two dimensions, the variation of the density of states, $N(E)$ as a function of energy E , is the best represented by



47. The energy dependence of the density of states for a two dimensional non-relativistic electron gas is given by, $g(E) = CE^n$, where C is constant. The value of n is _____ [GATE 2015]
48. Given that the Fermi energy of gold is 5.54 eV, the number density of electrons is _____ $\times 10^{28} \text{ m}^{-3}$ (upto one decimal places) [GATE 2015]
 (Mass of electron = $9.11 \times 10^{-31} \text{ kg}$; $h = 6.626 \times 10^{-34} \text{ J.s}$; $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$)



49. A thin metal film of dimension $2 \text{ mm} \times 2 \text{ mm}$ contains 4×10^{12} electrons. The magnitude of the Fermi wavevector of the system, in the free electron approximation, is [NET Dec. 2015]
 (a) $2\sqrt{\pi} \times 10^7 \text{ cm}^{-1}$ (b) $\sqrt{2\pi} \times 10^7 \text{ cm}^{-1}$ (c) $\sqrt{\pi} \times 10^7 \text{ cm}^{-1}$ (d) $2\pi \times 10^7 \text{ cm}^{-1}$
50. A metal has free electron density $n = 10^{29} \text{ m}^{-3}$. Which of the following wavelengths will excite plasma oscillations?
 (a) $0.033 \mu\text{m}$ (b) $0.330 \mu\text{m}$ (c) $3.300 \mu\text{m}$ (d) $33.000 \mu\text{m}$
51. The Bloch theorem states that within a crystal, the wavefunction, $\psi(\vec{r})$, of an electron has the form
 (a) $\psi(\vec{r}) = u(\vec{r})e^{i\vec{k}\cdot\vec{r}}$ where $u(\vec{r})$ is an arbitrary function and $\vec{k}$ is an arbitrary vector.
 (b) $\psi(\vec{r}) = u(\vec{r})e^{i\vec{G}\cdot\vec{r}}$ where $u(\vec{r})$ is an arbitrary function and $\vec{G}$ is a reciprocal lattice vector.
 (c) $\psi(\vec{r}) = u(\vec{r})e^{i\vec{G}\cdot\vec{r}}$ where $u(\vec{r}) = u(\vec{r} + \vec{A})$, $\vec{A}$ is a lattice vector and $\vec{G}$ is a reciprocal lattice vector.
 (d) $\psi(\vec{r}) = u(\vec{r})e^{i\vec{k}\cdot\vec{r}}$ where $u(\vec{r}) = u(\vec{r} + \vec{A})$, $\vec{A}$ is a lattice vector and $\vec{k}$ is an arbitrary vector.

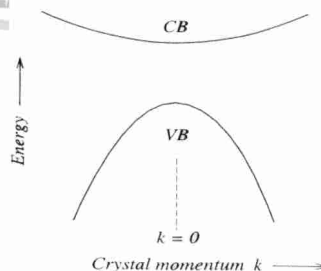
Common data Q. 52 and Q.53:

The tight binding energy dispersion ($E-k$) relation for electrons in a one-dimensional array of atoms having lattice constant a and total length L is:

$$E = E_0 - \beta - 2\gamma \cos(ka)$$

Where E_0 , β and γ are constants and k is the wave-vector.

52. The density of states of electrons (including spin degeneracy) in the band is given by
 (a) $\frac{L}{\pi ya \sin(ka)}$ (b) $\frac{L}{2\pi ya \sin(ka)}$ (c) $\frac{L}{2\pi ya \cos(ka)}$ (d) $\frac{L}{\pi ya \cos(ka)}$
53. The effective mass of electrons in the band is given by
 (a) $\frac{\hbar^2}{\gamma a^2 \cos(ka)}$ (b) $\frac{\hbar^2}{2\gamma a^2 \cos(ka)}$ (c) $\frac{\hbar^2}{\gamma a^2 \sin(ka)}$ (d) $\frac{\hbar^2}{2\gamma a^2 \cos(ka)}$
54. Suppose the energy band of a certain pure crystalline solid is as shown in the figure below, where the energy (E) varies with crystal momentum (k) as $E \propto k^2$



At finite temperatures the bottom of the conduction band (CB) is partially filled with electrons (e) and the top of the valence band (VB) is partially filled with holes (h). If an electric field is applied to this solid, both e and h will start moving. If the time between collisions is the same for both e and h, then

- (a) e and h will move with the same speed in opposite directions
 (b) h will on an average achieve higher speed than e
 (c) e will on an average achieve higher speed than h
 (d) e and h will recombine and after a while there will be no flow of charges.



55. In a periodic potential given by $V(\vec{r}) = V(\vec{r} + \vec{R})$, where $\vec{R}$ is the lattice vector, the eigenstates of the Hamiltonian

$H = \frac{-\hbar^2}{2m} \nabla^2 + V(\vec{r})$ are $\psi_k(\vec{r}) = e^{i\vec{k} \cdot \vec{r}} u_k(\vec{r})$, where

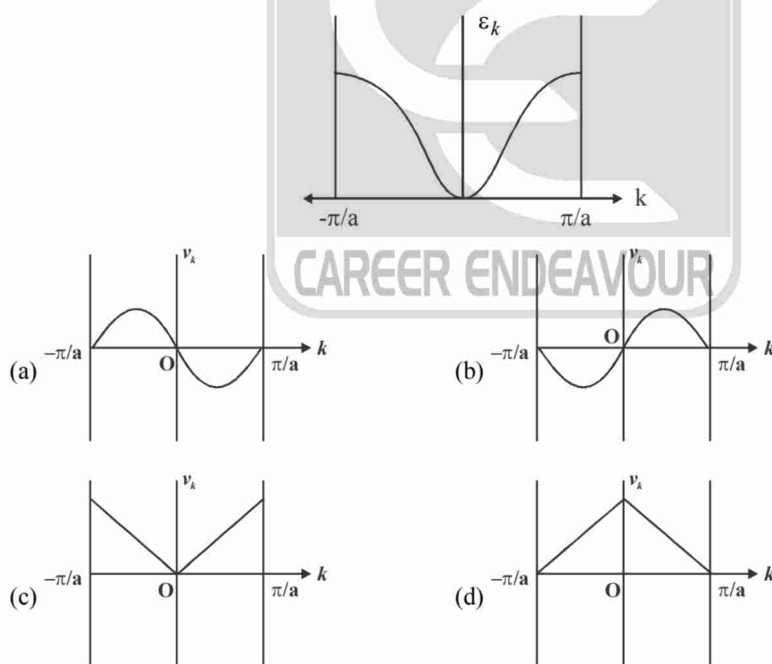
- (a) $u_k(\vec{r}) = e^{i\vec{k} \cdot \vec{R}} (\vec{k} \neq \vec{k}')$ (b) $u_k(\vec{r}) = e^{i\vec{k} \cdot \vec{R}} u_k\left(\vec{r} + \frac{\vec{R}}{3}\right)$
 (c) $u_k(\vec{r}) = u_k\left(\vec{r} + \frac{\vec{R}}{2}\right)$ (d) $u_k(\vec{r}) = u_k(\vec{r} + \vec{R})$

56. In a band structure calculation, the dispersion relation for electrons is found to be

$$\epsilon_k = \beta (\cos k_x a + \cos k_y a + \cos k_z a)$$

where β is a constant and a is the lattice constant. The effective mass at the boundary of the first Brillouin zone is

- (a) $\frac{2\hbar^2}{5\beta a^2}$ (b) $\frac{4\hbar^2}{5\beta a^2}$ (c) $\frac{\hbar^2}{2\beta a^2}$ (d) $\frac{\hbar^2}{3\beta a^2}$ (e) none of these
57. The energy, ϵ_k for band electrons as a function of the wave vector, k in the first Brillouin zone $\left(-\frac{\pi}{a} \leq k \leq \frac{\pi}{a}\right)$ of a one dimensional monatomic lattice is shown as (a is lattice constant)



58. For a perfect free-electron gas in a metal, the magnitudes of phase velocity (v_p) and group velocity (v_g) are such that:
- (a) $v_p = v_g$ (b) $v_p = \frac{1}{2} v_g$ (c) $v_p = \sqrt{2} v_g$ (d) $v_p = 2 v_g$
59. Consider an electron in a b.c.c. lattice with lattice constant a . A single particle wavefunction that satisfies the Bloch theorem will have the form $f(\vec{r}) \exp(i\vec{k} \cdot \vec{r})$, with $f(\vec{r})$ being
- (a) $1 + \cos\left[\frac{2\pi}{a}(x+y-z)\right] + \cos\left[\frac{2\pi}{a}(-x+y+z)\right] + \cos\left[\frac{2\pi}{a}(x-y+z)\right]$
 (b) $1 + \cos\left[\frac{2\pi}{a}(x+y)\right] + \cos\left[\frac{2\pi}{a}(y+z)\right] + \cos\left[\frac{2\pi}{a}(z+x)\right]$
 (c) $1 + \cos\left[\frac{\pi}{a}(x+y)\right] + \cos\left[\frac{\pi}{a}(y+z)\right] + \cos\left[\frac{\pi}{a}(z+x)\right]$
 (d) $1 + \cos\left[\frac{\pi}{a}(x+y-z)\right] + \cos\left[\frac{\pi}{a}(-x+y+z)\right] + \cos\left[\frac{\pi}{a}(x-y+z)\right]$
60. The dispersion relation for electrons in an f.c.c. crystal is given, in the tight binding approximation by
- $$\varepsilon(k) = -4\varepsilon_0 \left[\cos\frac{k_x a}{2} \cos\frac{k_y a}{2} + \cos\frac{k_y a}{2} \cos\frac{k_z a}{2} + \cos\frac{k_z a}{2} \cos\frac{k_x a}{2} \right]$$
- where ' a ' is the lattice constant and ε_0 is a constant with the dimension of energy. The x-component of the velocity of the electrons at $\left(\frac{\pi}{a}, 0, 0\right)$ is
- (a) $-\frac{2\varepsilon_0 a}{h}$ (b) $\frac{2\varepsilon_0 a}{h}$ (c) $-\frac{4\varepsilon_0 a}{h}$ (d) $\frac{4\varepsilon_0 a}{h}$
61. Which of the following is the best technique for measuring the effective mass of an electron in a semiconductor?
- (a) Resistivity measurements (b) X-rays diffraction experiment
 (c) Cyclotron resonance (d) Millikan's oil drop experiment
62. In the basic band structure theory of crystalline solids, which of the following leads to energy gaps in the allowed electronic energy values?
- (a) Electron spin (b) Bragg reflection
 (c) Electron-electron interaction (d) Electron-phonon interaction
63. Given that tight binding dispersion relation $E(k) = E_0 + A \sin^2\left(\frac{ka}{2}\right)$, where E_0 and A are constant and a is the lattice parameter. What is the group velocity of an electron at the second Brillouin zone boundary?
- (a) 0 (b) $\frac{a}{h}$ (c) $\frac{2a}{h}$ (d) $\frac{a}{2h}$ [JEST 2015]
64. The dispersion relation for electrons in the conduction band of a n -type semiconductor has the form $E(k) = ak^2 + b$ where a and b are constant. It was observed that the cyclotron resonance frequency of such electrons is $\omega_0 = 1.8 \times 10^{11} \text{ rad s}^{-1}$, when placed in a magnetic field $B = 0.1 \text{ W m}^{-2}$. It follows that the constant a must be about
- (a) 10^{-36} (b) 10^{-28} (c) 10^{-32} (d) 10^{-38} [TIFR 2016]



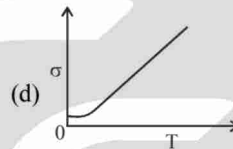
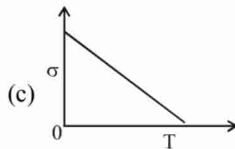
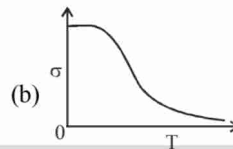
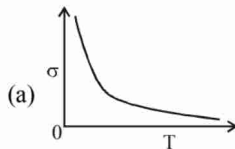
65. The dispersion relation of electrons in a 3-dimensional lattice in the tight binding approximation is given by, $\epsilon_k = \alpha \cos k_x a + \beta \cos k_y a + \gamma \cos k_z a$ where a is the lattice constant and α, β, γ are constants with dimension of energy. The effective mass tensor at the corner of the first Brillouin zone $\left(\frac{\pi}{a}, \frac{\pi}{a}, \frac{\pi}{a}\right)$ is [NET Dec. 2015]
- (a) $\frac{\hbar^2}{a^2} \begin{pmatrix} -\frac{1}{\alpha} & 0 & 0 \\ 0 & -\frac{1}{\beta} & 0 \\ 0 & 0 & \frac{1}{\gamma} \end{pmatrix}$ (b) $\frac{\hbar^2}{a^2} \begin{pmatrix} -\frac{1}{\alpha} & 0 & 0 \\ 0 & -\frac{1}{\beta} & 0 \\ 0 & 0 & -\frac{1}{\gamma} \end{pmatrix}$ (c) $\frac{\hbar^2}{a^2} \begin{pmatrix} \frac{1}{\alpha} & 0 & 0 \\ 0 & \frac{1}{\beta} & 0 \\ 0 & 0 & \frac{1}{\gamma} \end{pmatrix}$ (d) $\frac{\hbar^2}{a^2} \begin{pmatrix} \frac{1}{\alpha} & 0 & 0 \\ 0 & \frac{1}{\beta} & 0 \\ 0 & 0 & -\frac{1}{\gamma} \end{pmatrix}$
66. The energy of an electron in a band as a function of its wave vector $\mathbf{k}$ is given by $E(k) = E_0 - B(\cos k_x a + \cos k_y a + \cos k_z a)$, where E_0, B and a are constants. The effective mass of the electron near the bottom of the band is
- (a) $\frac{2\hbar^2}{3Ba^2}$ (b) $\frac{\hbar^2}{3Ba^2}$ (c) $\frac{\hbar^2}{2Ba^2}$ (d) $\frac{\hbar^2}{Ba^2}$
67. The energy vs. wave vector ($E - k$) relationship near the bottom of a band for a solid can be approximated as $E = A(ka)^2 + B(ka)^4$, where the lattice constant $a = 2.1 \text{ \AA}$. The values of A and B are $6.3 \times 10^{-19} \text{ J}$ and $3.2 \times 10^{-20} \text{ J}$, respectively. At the bottom of the conduction band, the ratio of the effective mass of the electron to the mass of free electron is _____. (Give your answer upto two decimal places) [GATE 2016]
- (Take $\hbar = 1.05 \times 10^{-34} \text{ J-s}$, mass of free electron $= 9.1 \times 10^{-31} \text{ kg}$).
68. For an electron moving through a one-dimensional periodic lattice of periodicity a , which of the following corresponds to an energy eigenfunction consistent with Bloch's theorem? [NET Dec. 2015]
- (a) $\psi(x) = A \exp\left(i\left[\frac{\pi x}{a} + \cos\left(\frac{\pi x}{2a}\right)\right]\right)$ (b) $\psi(x) = A \exp\left(i\left[\frac{\pi x}{a} + \cos\left(\frac{2\pi x}{a}\right)\right]\right)$
- (c) $\psi(x) = A \exp\left(i\left[\frac{2\pi x}{a} + i \cosh\left(\frac{2\pi x}{a}\right)\right]\right)$ (d) $\psi(x) = A \exp\left(i\left[\frac{\pi x}{2a} + i\left[\frac{\pi x}{2a}\right]\right]\right)$
69. Consider electrons in graphene, which is a planar monatomic layer of carbon atoms. If the dispersion relation of the electrons is taken to be $\epsilon(k) = ck$ (where c is constant) over the entire k -space, then the Fermi energy ϵ_F depends on the number density of electrons ρ as [NET June 2016]
- (a) $\epsilon_F \propto \rho^{1/2}$ (b) $\epsilon_F \propto \rho$ (c) $\epsilon_F \propto \rho^{2/3}$ (d) $\epsilon_F \propto \rho^{1/3}$
70. The band energy of an electron in a crystal for a particular k -direction has the form $\epsilon(k) = A - B \cos 2ka$, where A and B are positive constants and $0 < ka < \pi$. The electron has a hole-like behaviour over the following range of k : [NET June 2016]
- (a) $\frac{\pi}{4} < ka < \frac{3\pi}{4}$ (b) $\frac{\pi}{2} < ka < \pi$ (c) $0 < ka < \frac{\pi}{4}$ (d) $\frac{\pi}{2} < ka < \frac{3\pi}{4}$
71. The low-energy electronic excitations in a two-dimensional sheet of graphene is given by $E(\vec{k}) = \hbar v k$, where v is the velocity of the excitations. The density of states is proportional to [NET June 2015]
- (a) E (b) $E^{3/2}$ (c) $E^{1/2}$ (d) E^2



72. Consider a one-dimensional chain of atoms with lattice constant a . The energy of an electron with wave-vector k is $\varepsilon(k) = \mu - \gamma \cos(ka)$, where μ and γ are constants. If an electric field E is applied in the positive x -direction, the time dependent velocity of an electron is (in the following B is the constant) [NET Dec. 2016]
- (a) proportional to $\cos\left(B - \frac{eE}{\hbar}at\right)$ (b) proportional to E
- (c) independent of E (d) proportional to $\sin\left(B - \frac{eE}{\hbar}at\right)$
73. The electrons in graphene can be thought of as a two-dimensional gas with a linear energy-momentum relation $E = |\vec{p}|v$, where $\vec{p} = (p_x, p_y)$ and v is a constant. If ρ is the number of electrons per unit area, the energy per unit area is proportional to [NET Dec. 2016]
- (a) $\rho^{3/2}$ (b) ρ (c) $\rho^{1/3}$ (d) ρ^2
74. In two dimensions two metals A and B, have the number density of free electrons in the ratio $n_A : n_B = 1 : 2$. The ratio of their Fermi energies is [TIFR 2017]
- (a) 2 : 3 (b) 1 : 2 (c) 1 : 4 (d) 1 : 8
75. Consider a 2-dimensional electron gas with a density of 10^{19} m^{-2} . The Fermi energy of the system is _____ eV. (up to two decimal places). [GATE 2017]
- ($m_e = 9.31 \times 10^{-31} \text{ kg}$, $\hbar = 6.626 \times 10^{-34} \text{ Js}$, $e = 1.602 \times 10^{-19} \text{ C}$)
76. Assume that the crystal structure of metallic copper (Cu) results in a density of atoms $\rho_{\text{Cu}} = 8.46 \times 10^{28} \text{ m}^{-3}$. Each Cu atom in the crystal donates one electron to the conduction band, which leads, for the 3-D Fermi gas, to a density of states [TIFR 2017]
- $$g(\varepsilon) = \frac{1}{2\pi^2} \left(\frac{2m^*}{\hbar^2} \right)^{3/2} \varepsilon^{1/2}$$
- where m^* is the effective mass of the conduction electrons. In the low temperature limit (i.e. $T = 0 \text{ K}$), find the Fermi energy E_F , in units of eV. You may assume m^* to be equal to the free electron mass m_e .
77. Electrons in a metal are scattered by both impurities and phonons. The impurity scattering time is $8 \times 10^{-12} \text{ s}$ and the phonon scattering time is $2 \times 10^{-12} \text{ s}$. Taking the density of electrons to be $3 \times 10^{14} \text{ m}^{-3}$, find the conductivity of the metal in units of $\text{A V}^{-1} \text{ m}^{-1}$. [Assume that the effective mass of the electrons is the same as that of a free electron]. [TIFR 2017]
78. The atomic mass and mass density of Sodium are 23 and 0.968 g cm^{-3} , respectively. The number density of valence electrons is _____ $\times 10^{22} \text{ cm}^{-3}$. (Up to two decimal places.) [GATE 2017]
- (Avogadro number, $N_A = 6.022 \times 10^{23}$).
79. Consider a one-dimensional lattice with a weak periodic potential $U(x) = U_0 \cos\left(\frac{2\pi x}{a}\right)$. The gap at the edge of the Brillouin zone $\left(k = \frac{\pi}{a}\right)$ is: [GATE 2017]
- (a) U_0 (b) $\frac{U_0}{2}$ (c) $2U_0$ (d) $\frac{U_0}{4}$



80. The energy gap and lattice constant of an indirect band gap semiconductor are 1.875 eV ; 0.52 nm, respectively. For simplicity take the dielectric constant of the material to be unity. When it is excited by broadband radiation, an electron initially in the valence band at $k = 0$ makes a transition to the conduction band. The wavevector of the electron in the conduction band, in terms of the wavevector $k_{\max}$ at the edge of the Brillouin zone, after the transition is closest to
[NET June 2017]
(a) $k_{\max}/10$ (b) $k_{\max}/100$ (c) $k_{\max}/1000$ (d) 0
81. The electrical conductivity of copper is approximately 95% of the electrical conductivity of silver, while the electron density in silver is approximately 70% of the electron density in copper. In Drude's model, the approximate ratio $\tau_{\text{Cu}}/\tau_{\text{Ag}}$ of the mean collision time in copper (τ_{Cu}) to the mean collision time in silver (τ_{Ag}) is
(a) 0.44 (b) 1.50 (c) 0.33 (d) 0.66 [NET June 2017]
82. Which one of the following schematic curves best represents the variation of conductivity σ of a metal with temperature T ?



83. A white dwarf star has volume V and contains N electrons so that the density of electrons is $n = \frac{N}{V}$. Taking the temperature of the star to be 0 K, the average energy per electron in the star is $\epsilon_0 = \frac{3h^2}{10m} (3\pi^2 n)^{2/3}$, where m is the mass of the electron. The electronic pressure in the star is
(a) $n \epsilon_0$ (b) $2\pi \epsilon_0$ (c) $\frac{1}{3} n \epsilon_0$ (d) $\frac{2}{3} n \epsilon_0$
84. If X is the dimensionality of a free electron gas, the energy (E) dependence of density of states is given by $E^{\frac{1}{2}X-Y}$, where Y is _____. [GATE 2018]
85. The energy dispersion for electron in one dimensional lattice with lattice parameter a is given by

$$E(k) = E_0 - \frac{1}{2} W \cos ka,$$

where W and E_0 are constants. The effective mass of the electron near the bottom of the band is

- (a) $\frac{2\hbar^2}{Wa^2}$ (b) $\frac{\hbar^2}{Wa^2}$ (c) $\frac{\hbar^2}{2Wa^2}$ (d) $\frac{\hbar^2}{4Wa^2}$ [GATE 2018]
86. For a metal, the electron density is $6.4 \times 10^{28} \text{ m}^{-3}$. The Fermi energy is _____ eV.
($\hbar = 6.626 \times 10^{-34} \text{ Js}$, $m_e = 9.11 \times 10^{-31} \text{ kg}$, $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$)
(Specify your answer in electron volts (eV) upto one digit after the decimal point)



87. The Fermi energy ε_F in metals depends on the number density n_c of mobile electrons, which may be thought of as a free Fermi gas. If n_c of one metal is larger by a factor of 1000 compared to another, then in comparison, its Fermi energy is
 (a) 1000 times larger (b) smaller by a factor of 1/100
 (c) 100 times larger (d) 10 times larger
88. A metallic nanowire of length l is approximated as a one-dimensional lattice of N atoms with lattice spacing a . If the dispersion of electrons in the lattice is given as $E(k) = E_0 - 2t \cos ka$, where E_0 and t are constants, then the density of states inside the nanowire depends on E as [NET Dec. 2017]
 (a) $N^3 \sqrt{\frac{t^2}{E - E_0}}$ (b) $\sqrt{\left(\frac{E - E_0}{2t}\right)^2 - 1}$ (c) $N^3 \sqrt{\frac{E - E_0}{t^2}}$ (d) $\frac{N}{\sqrt{(2t)^2 - (E - E_0)^2}}$
89. The dispersion relation for the electrons in the conduction band of a semiconductor is given by $E = E_0 + \alpha k^2$, where α and E_0 are constants. If ω_c is the cyclotron resonance frequency of the conduction band electrons in a magnetic field B , the value of α is [NET June 2018]
 (a) $\frac{\hbar^2 \omega_c}{4eB}$ (b) $\frac{2\hbar^2 \omega_c}{eB}$ (c) $\frac{\hbar^2 \omega_c}{eB}$ (d) $\frac{\hbar^2 \omega_c}{2eB}$
90. The energy-wavevector (E - k) dispersion relation for a particle in two dimensions is $E = Ck$, where C is a constant. If its density of states $D(E)$ is proportional to E^p then the value of p is [GATE 2019]
91. In a certain two-dimensional lattice, the energy dispersion of the electron is [GATE 2019]

$$\varepsilon(\vec{k}) = -2t \left[\cos k_x a + 2 \cos \frac{1}{2} k_x a \cos \frac{\sqrt{3}}{2} k_y a \right],$$
 where $\vec{k} = (k_x, k_y)$ denotes the wave vector, a is the lattice constant and t is a constant in units of eV. In this lattice the effective mass energy tensor m_{ij} of electrons calculated at the centre of the Brillouin zone has the form $m_{ij} = \frac{\hbar^2}{ta^2} \begin{pmatrix} \alpha & 0 \\ 0 & \alpha \end{pmatrix}$. The value of α (rounded off to three decimal places) is _____.
92. The potential in a divalent solid at a particular temperature is represented by a one-dimensional periodic model. The solid should behave electrically as:
 (a) semiconductor (b) a conductor
 (c) an insulator (d) a superconductor
93. In a one-dimensional Kroning Penny model, the total number of possible wave functions is equal to:
 (a) twice the number of unit cells
 (b) number of unit cells
 (c) half the number of unit cells
 (d) independent of the number of unit cells
94. In a crystal of N primitive cells, each cell contains two monovalent atoms. The highest occupied energy band of the crystal is:
 (a) one-fourth filled (b) one-third filled (c) half filled (d) completely filled



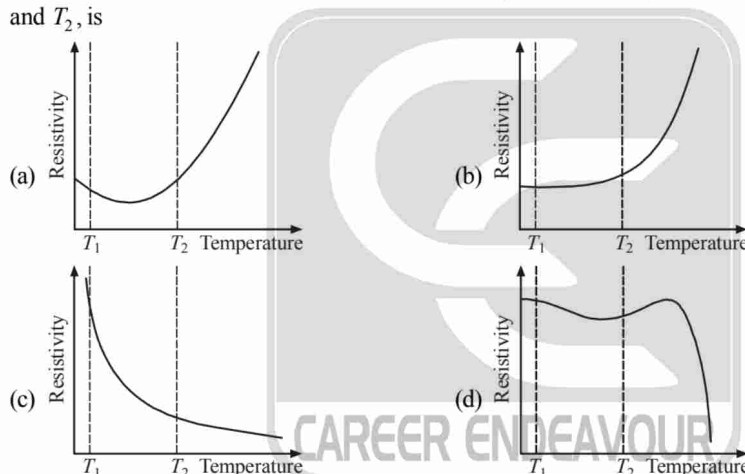
95. A particle of mass m moves in a lattice along the x -axis in a periodic potential $V(x) = V(x + d)$ with periodicity d . The corresponding Brillouin zone extends from $-k_0$ to k_0 with these two k -points being equivalent. If a weak force F in the x -direction is applied to the particle, it starts a periodic motion with time period T . Using the equation of motion $F = \frac{dp_{\text{crystal}}}{dt}$ for a particle moving in a band, where p_{crystal} is the crystal momentum of the particle, the period T is found to be (h is Planck constant) [GATE 2019]

(a) $\sqrt{\frac{2md}{F}}$ (b) $2\sqrt{\frac{2md}{F}}$ (c) $\frac{2h}{Fd}$ (d) $\frac{h}{Fd}$

96. Consider a one-dimensional non-magnetic crystal with one atom per unit cell. Assume that the valence electrons (i) do not interact with each other and (ii) interact weakly with the ions. If n is the number of valence electrons per unit cell, then at 0 K. [GATE 2020]

- (a) the crystal is metallic for even values of n (b) the crystal is metallic for any value of n
(c) the crystal is non-metallic for any value of n (d) the crystal is metallic for odd values of n

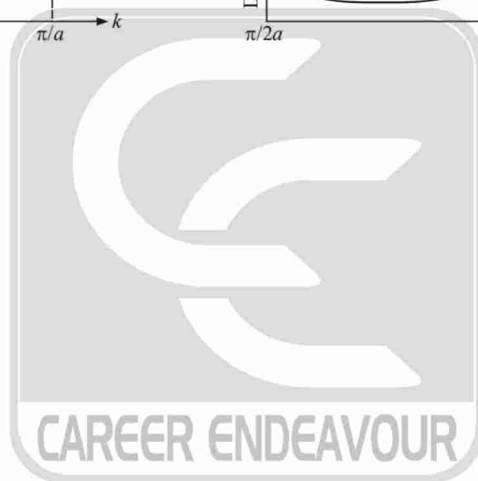
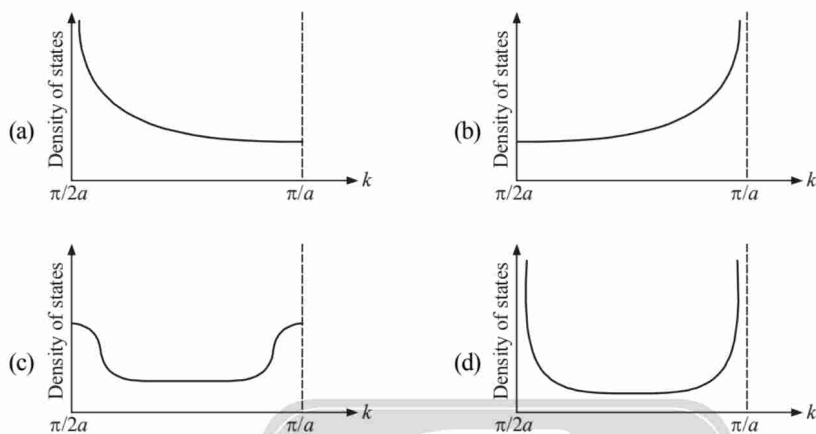
97. The temperature variation of the resistivity of four materials are shown in the following graphs. The material that would make the most sensitive temperature sensor, when used at temperature between T_1 and T_2 , is [NET Nov. 2020]



98. A certain two-dimensional solid crystallises to a square monoatomic lattice with lattice constant ' a '. Each atom can contribute an integer number of free conduction electrons. The minimum number of electrons each atom must contribute such that the free electron Fermi circle at zero temperature encloses the first Brillouin zone completely, is [NET Nov. 2020]
- (a) 3 (b) 1 (c) 4 (d) 2



99. A tight binding model of electrons in one dimension has the dispersion relation $\varepsilon(k) = -2t(1 - \cos ka)$, where $t > 0$, a is the lattice constant and $-\frac{\pi}{a} < k < \frac{\pi}{a}$. Which of the following figures best represents the density of states over the range $\frac{\pi}{2a} \leq k < \frac{\pi}{a}$? [NET Nov. 2020]





- The ratio of the mobility to the diffusion coefficient in a semiconductor has the units:
(a) V^{-1} (b) $cm.V^{-1}$ (c) $V.cm^{-1}$ (d) $V.s$
- The bandgap of silicon at room temperature is:
(a) 1.3 eV (b) 0.7 eV (c) 1.1 eV (d) 1.4 eV
- The probability that an electron in a metal occupies the Fermi-level at any temperature (> 0 K):
(a) 0 (b) 1 (c) 0.5 (d) 1.0
- Which one of the following is a trivalent material?
(a) Antimony (b) Phosphorus (c) Arsenic (d) Boron
- The materials not having negative temperature coefficient of resistivity are
(a) Metals (b) Semiconductors (c) Insulators (d) None of the above.
- The Ohm's law for conduction in metals is:
(a) $J = \sigma E$ (b) $J \propto \sigma E$ (c) $J = E / \sigma$ (d) $J \propto E / \sigma$
- N-type silicon is obtained by doping silicon with:
(a) Germanium (b) Aluminium (c) Boron (d) Phosphorus
- The band-gap of silicon at 300 K is:
(a) 1.36 eV (b) 1.10 eV (c) 0.80 eV (d) 6.67 eV
- The drift velocity of electrons in silicon:
(a) Is proportional to the electric field for all values of electric field.
(b) Is independent of the electric field.
(c) Increases at low values of electric field and decreases at high values of electric field exhibiting negative differential resistance.
(d) Increases linearly with electric field at low values of electric field and gradually saturates at higher values of electric field.
- The free electron density in a conductor is $(1/1.6) \times 10^{22} \text{ cm}^{-3}$. The electron mobility is $10 \text{ cm}^2/\text{V s}$. What is the value of its resistivity?
(a) 10^{-4} Wm (b) $1.6 \times 10^{-2} \text{ Wm}$ (c) $10^{-4} \text{ } \Omega\text{cm}$ (d) $10^{-4} \text{ } \Omega \text{ cm}^{-1}$
- The net charge of an n-type semiconductor is
(a) positive (b) zero (c) negative (d) dependent on the dopant density
- When a pentavalent impurity is added to Si, it becomes
(a) an insulator (b) a conductor
(c) an intrinsic semiconductor (d) an n-type semiconductor
- When a pure semiconductor is heated, its resistance
(a) increases (b) decreases linearly
(c) decreases exponentially (d) remains the same
- Given that the band gap of cadmium sulphide is 2.25 eV, the maximum photon wavelength, for electron-hole pair generation will be
(a) $5400 \text{ } \mu\text{m}$ (b) $540 \text{ } \mu\text{m}$ (c) $5400 \text{ } \text{\AA}$ (d) $540 \text{ } \text{\AA}$



15. LED is a
(a) p-n diode (b) Thermistor (c) Gate (d) Transistor
16. The effective mass of an electron in a semiconductor can be:
(a) negative near the bottom of the band (b) a scalar quantity with a small magnitude
(c) zero at the center of the band (d) negative near the top of the band
17. The effective mass of an electron in a semiconductor
(a) can never be positive (b) can never be negative
(c) can be positive or negative (d) depends on its spin
18. An n-type semiconductor has an electron concentration of $3 \times 10^{20} \text{ m}^{-3}$. If the electron drift velocity is 100 ms^{-1} in an electric field of 200 Vm^{-1} , the conductivity (in $\text{W}^{-1}\text{m}^{-1}$) of this material is:
(a) 24 (b) 36 (c) 48 (d) 96
19. Which one of the following is NOT a correct statement about semiconductors?
(a) The electrons and holes have different mobilities in a semiconductor
(b) In an n-type semiconductor, the Fermi level lies closer to the conduction band edge
(c) Silicon is a direct band gap semiconductor
(d) Silicon has diamond structure
20. Compared to a p-n junction with $N_A = N_D = 10^{14} / \text{cm}^3$, which one of the following statement is TRUE for a p-n junction with $N_A = N_D = 10^{20} / \text{cm}^3$?
(a) Reverse breakdown voltage is lower and depletion capacitance is lower.
(b) Reverse breakdown voltage is higher and depletion capacitance is lower.
(c) Reverse breakdown voltage is lower and depletion capacitance is higher.
(d) Reverse breakdown voltage is higher and depletion capacitance is higher.
21. Silicon is doped with boron to a concentration of $4 \times 10^{17} \text{ atoms/cm}^3$. Assume the intrinsic carrier concentration of silicon to be $1.5 \times 10^{10} / \text{cm}^3$ and the value of kT/q to be 25 mV at 300 K. Compared to un-doped silicon, the Fermi level of doped silicon:
(a) Goes down by 0.13 eVs (b) Goes up by 0.13 eV
(c) Goes down by 0.427 eV (d) Goes up by 0.427 eV
22. The electron and hole concentrations in an intrinsic semiconductor are n_i per cm^3 at 300K. Now, if acceptor impurities are introduced with a concentration of N_A per cm^3 (where $N_A \gg n_i$), the electron concentration per cm^3 at 300 K will be:
(a) n_i (b) $n_i + N_A$ (c) $N_A - n_i$ (d) $\frac{n_i^2}{N_A}$
23. In a p^+n junction diode under reverse bias, the magnitude of electric field is maximum at:
(a) The edge of the depletion region on the p-side (b) The edge of the depletion region on the n-side
(c) The p^+n junction (d) The centre of the depletion region on the n-side.
24. A P-N junction has a built-in potential of 0.8 V. The depletion layer width at a reverse bias of 1.2 V is $2 \mu\text{m}$. For a reverse bias of 7.2 V, the depletion layer width will be:
(a) $4 \mu\text{m}$ (b) $4.9 \mu\text{m}$ (c) $8 \mu\text{m}$ (d) $12 \mu\text{m}$
25. The Fermi level in an intrinsic semiconductor at zero temperature lies
(a) in the conduction band
(b) at the top of the valence band
(c) at the bottom of the conduction band
(d) in the energy gap between the valence and the conduction bands



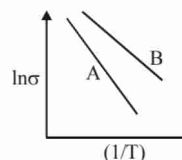
26. A silicon PN junction diode under reverse bias has depletion region of width $10\ \mu\text{m}$. The relative permittivity of Silicon, $\epsilon_r = 11.7$ and the permittivity of free space $\epsilon_0 = 8.85 \times 10^{-12}\ \text{F/m}$. The depletion capacitance of the diode per square meter is:
 (a) $100\ \mu\text{F}$ (b) $10\ \mu\text{F}$ (c) $1\ \mu\text{F}$ (d) $20\ \mu\text{F}$
27. In an abrupt p-n junction, the doping concentrations on the p-side and n-side are $N_A = 9 \times 10^{16}/\text{cm}^3$ and $N_D = 1 \times 10^{16}/\text{cm}^3$ respectively. The p-n junction is reverse biased and the total depletion width is $3\ \mu\text{m}$. The depletion width on the p-side is:
 (a) $2.7\ \mu\text{m}$ (b) $0.3\ \mu\text{m}$ (c) $2.25\ \mu\text{m}$ (d) $0.75\ \mu\text{m}$
28. A long specimen of p-type semiconductor material:
 (a) Is positively charged (b) Is electrically neutral
 (c) Has an electric field directed along its length (d) Acts as a dipole
29. In a P-type silicon sample, the hole concentration is $2.25 \times 10^{15}/\text{cm}^3$. If the intrinsic carrier concentration is $1.5 \times 10^{10}/\text{cm}^3$, the electron concentration is:
 (a) Zero (b) $10^{10}/\text{cm}^3$ (c) $10^5/\text{cm}^3$ (d) $1.5 \times 10^{25}/\text{cm}^3$
30. An infra-red LED is usually fabricated from:
 (a) Ge (b) Si (c) GaAs (d) GaAsP
31. Which of the following statements is/are true for a good conductor of electricity?
 1. Its conductivity decreases with increasing temperature.
 2. Number of free electrons is around $10^{28}\ \text{m}^{-3}$.
 3. Its conductivity decreases with addition of impurities.
 4. It is a good conductor of heat also.
 (a) 1, 2, 3 and 4 (b) 1 only (c) 2 and 3 only (d) 3 and 4 only
32. Consider the following statements:
 The conductivity of a metal has negative temperature coefficient since:
 1. The electron concentration increases with temperature.
 2. The electron mobility decreases with temperature.
 3. The electron-lattice scattering rate increases with temperature.
 Which of the above statements is/are correct?
 (a) 1 only (b) 1 and 2 (c) 2 and 3 (d) 3 only
33. Consider the following:
 1. Si 2. Ge 3. GaAs 4. InP
 Which of the above semiconductors should be used for making highly efficient photodiodes?
 (a) 1 and 4 only (b) 3 and 4 only (c) 1, 3 and 4 (d) 2, 3 and 4.
34. In a material, the Fermi level is located between the centre of the forbidden band and the conduction band. Then what is that material?
 (a) A p-type semiconductor (b) An n-type semiconductor
 (c) An intrinsic semiconductor (d) An insulator.
35. An intrinsic semiconductor with energy gap $1\ \text{eV}$ has a carrier concentration N at temperature $200\ \text{K}$. Another intrinsic semiconductor has the same value of carrier concentration N at temperature $600\ \text{K}$. What is the energy gap value for the second semiconductor?
 (a) $(1/3)\ \text{eV}$ (b) $(3/2)\ \text{eV}$ (c) $3\ \text{eV}$ (d) $9\ \text{eV}$
36. Consider the following statements:
 n-type of silicon can be
 1. Formed by adding impurity of phosphorus
 2. Formed by adding impurity of arsenic
 3. Formed by adding impurity of boron.
 4. Formed by adding impurity of aluminium.
 Which of the statements given above are correct?
 (a) 1 and 3 only (b) 3 and 4 only (c) 1 and 2 only (d) 1, 2, 3 and 4.



37. In a step-graded p-n junction diode, what is the ratio of depletion-region penetration depths into p and n regions (if the ratio of acceptor to donor impurity atoms densities is 1:2)?
 (a) 2:1 (b) 4:1 (c) 1:2 (d) 1:4
38. Match **List-I** with **List-II** and select the correct answer using the code given below the lists:
- | List-I (Item) | | | | | List-II (Position) |
|--|--|--|--|--|---|
| A. Donor energy band | | | | | 1. At the middle of the forbidden energy gap. |
| B. Fermi level of p-type semiconductor at room temperature | | | | | 2. Close to the conduction band. |
| C. Acceptor energy band | | | | | 3. Very close to the valance band. |
| D. Fermi level in intrinsic semiconductor | | | | | 4. Close to the valence band. |
- | | A | B | C | D |
|-----|----------|----------|----------|----------|
| (a) | 4 | 3 | 2 | 1 |
| (b) | 2 | 1 | 4 | 3 |
| (c) | 4 | 1 | 2 | 3 |
| (d) | 2 | 3 | 4 | 1 |
39. The depletion layer in a p-n junction is made of which of the following?
 (a) Ionized donors in p-side and ionized acceptors in n-side.
 (b) Ionized acceptors in p-side and ionized donors in n-side.
 (c) Accumulated holes in p-side and accumulated electrons in n-side.
 (d) Accumulated electrons in p-side and accumulated holes in n-side.
40. Match the **List-I (Current)** with **List-II (Variation)** and select the correct answer using the code given below the lists:
- | List-I (Current) | List-II (Variation) |
|-------------------------------|----------------------------|
| A. Hole diffusion current | 1. $n.E$ |
| B. Electron drift current | 2. $p.E$ |
| C. Hole drift current | 3. $-dp/dx$ |
| D. Electron diffusion current | 4. dn/dx |
- (a) A-2, B-1, C-3, D-4 (b) A-3, B-4, C-2, D-1
 (c) A-2, B-4, C-3, D-1 (d) A-3, B-1, C-2, D-4
41. A thin resistive film having length (l), width (w) and thickness (t) is used as a resistor (R_1) for conducting current in the direction of l . If the film is connected to serve as a resistor (R_2) for conducting current in the direction of w , then what is the value of R_1/R_2 .
 (a) l/w (b) w/l (c) l^2/w^2 (d) w^2/l^2 .
42. Match **List-I (Type of Material)** with **List-II (Type of Bonding)** and select the correct answer using the codes given below the lists:
- | List-I (Type of Material) | List-II (Type of Bonding) |
|----------------------------------|----------------------------------|
| A. Elemental semiconductor | 1. Ionic |
| B. Hydrogen molecule | 2. Covalent |
| C. Copper | 3. Van der Waals' |
| D. AgI | 4. Metallic. |
- Codes:**
- | | | | | | | | | | |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| (a) | A-3 | B-2 | C-1 | D-4 | (b) | A-2 | B-3 | C-1 | D-4 |
| (c) | A-2 | B-3 | C-4 | D-1 | (d) | A-3 | B-4 | C-2 | D-1 |
43. Depletion capacitance in a diode depends on:
 1. Applied junction voltage. 2. Junction built-in potential
 3. Current through junction 4. Doping profile across the junction
 Select the correct answer using the codes given below:
 (a) 1 and 2 (b) 1 and 3 (c) 1, 2 and 4 (d) 2, 3 and 4



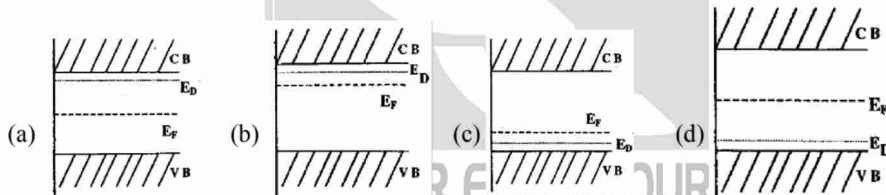
44. The depletion layer across a p⁺-n junction lies
 (a) mostly in the p region (b) mostly in the n region
 (c) equally in both p⁺ and n regions (d) Entirely in the p⁺ region.
45. Match **List-I (Crystal type)** with **List-II (Name of the solid)** and select the correct answer using the codes given below the Lists:
- | | |
|-------------------|--------------------|
| List-I | List-II |
| A. Ionic | 1. Solid argon |
| B. Covalent | 2. Copper |
| C. Metallic | 3. Silicon |
| D. Van der Waal's | 4. Sodium chloride |
- Codes:**
- | | |
|---------------------|---------------------|
| (a) A-3 B-4 C-2 D-1 | (b) A-4 B-3 C-1 D-2 |
| (c) A-3 B-4 C-1 D-2 | (d) A-4 B-3 C-2 D-1 |
46. The increasing temperature, the electrical conductivity would:
 (a) Increase in metals as well as in intrinsic semiconductor
 (b) Increase in metals but decrease in intrinsic semiconductor
 (c) Decrease in metals but increase in intrinsic semiconductor
 (d) Decrease in metals as well as in intrinsic semiconductors.
47. The band gap at 300°K of diamond cubic crystals of C, Si, Ge and Sn is 5.5, 1.2, 0.67 and 0.1 eV respectively. Identify the crystal which will have the highest electrical conductivity at 300 K
 (a) Ge (b) Sn (c) C (d) Si
48. The effective density of states at the conduction band edge and valence band of Ge is $1.04 \times 10^{19} \text{ cm}^{-3}$ at room temperature (300 K). Ge has an optical bandgap of 0.66 eV. The intrinsic carrier concentration (in cm^{-3}) in Ge at room temperature (300 K) is approximately:
 (a) 3×10^{10} (b) 3×10^{13} (c) 3×10^{16} (d) 6×10^{16}
49. An extrinsic semiconductor sample of cross-section A and length L is doped in such a way that the doping concentration varies as $N_D(x) = N_0 \exp\left(-\frac{x}{L}\right)$, where N_0 is a constant. Assume that the mobility μ of the majority carriers remains constant. The resistance R of the sample is given by:
 (a) $R = \frac{L}{A\mu e N_0} [\exp(1.0) - 1]$ (b) $R = \frac{L}{\mu e N_0} [\exp(1.0) - 1]$
 (c) $R = \frac{L}{A\mu e N_0} [\exp(-1.0) - 1]$ (d) $R = \frac{L}{A\mu e N_0}$
50. The temperature dependence of the electrical conductivity σ of two intrinsic semi-conductors A and B is shown in the figure. If E_A and E_B are the band gaps of A and B respectively, which one of the following is TRUE?
 (a) $E_A > E_B$
 (b) $E_A < E_B$
 (c) $E_A = E_B$
 (d) E_A and E_B both depend on temperature.



51. An intrinsic semiconductor with mass of a hole m_h and mass of an electron m_e is at a finite temperature T . If the top of the valence band energy is E_v and the bottom of the conduction band energy is E_c , the Fermi energy of the semiconductor is:
- (a) $E_F = \left(\frac{E_v + E_c}{2} \right) - \frac{3}{4} k_B T \ln \left(\frac{m_h}{m_e} \right)$ (b) $E_F = \left(\frac{k_B T}{2} \right) + \frac{3}{4} (E_v + E_c) \ln \left(\frac{m_h}{m_e} \right)$
- (c) $E_F = \left(\frac{E_v + E_c}{2} \right) + \frac{3}{4} k_B T \ln \left(\frac{m_h}{m_e} \right)$ (d) $E_F = \left(\frac{k_B T}{2} \right) - \frac{3}{4} (E_v + E_c) \ln \left(\frac{m_h}{m_e} \right)$
52. A silicon sample A is doped with 10^{18} atoms/cm³ of Boron. Another sample B of identical dimensions is doped with 10^{18} atoms/cm³ of Phosphorus. The ratio of electron to hole mobility is 3. The ratio of conductivity of the sample A to B is:
- (a) 3 (b) 1/3 (c) 2/3 (d) 3/2
53. The intrinsic carrier density at 300 K is $1.5 \times 10^{10} / \text{cm}^3$, in silicon. For n-type silicon doped to $2.25 \times 10^{15} \text{ atoms} / \text{cm}^3$, the equilibrium electron and hole densities are:
- (a) $n = 1.5 \times 10^{15} / \text{cm}^3$, $p = 1.5 \times 10^{10} / \text{cm}^3$ (b) $n = 1.5 \times 10^{10} / \text{cm}^3$, $p = 2.25 \times 10^{15} / \text{cm}^3$
- (c) $n = 2.25 \times 10^{15} / \text{cm}^3$, $p = 1.0 \times 10^5 / \text{cm}^3$ (d) $n = 1.5 \times 10^{10} / \text{cm}^3$, $p = 1.5 \times 10^{10} / \text{cm}^3$
54. A silicon sample is uniformly doped with 10^{16} phosphorous atoms/cm³ and 2×10^{16} boron atoms/cm³. If all the dopants are fully ionized, the material is:
- (a) n-type with carrier concentration of $10^{16} / \text{cm}^3$
- (b) p-type with carrier concentration of $10^{16} / \text{cm}^3$
- (c) p-type with carrier concentration of $2 \times 10^{16} / \text{cm}^3$
- (d) T_2 -will get damaged and T_1 will be safe.
55. In a uniformly doped abrupt p-n junction, the doping level of n-side is four (4) times the doping level of the p-side. The ratio of the depletion layer widths is:
- (a) 0.25 (b) 0.5 (c) 1.0 (d) 2.0
56. The doping concentration on the n-side of a p-n junction diode is enhanced. Which one of the following will get affected?
- (a) Width of the depletion region on n-side.
- (b) Width of the depletion region on p-side.
- (c) Width of the depletion region on both sides.
- (d) No change in width of depletion regions
57. Which one of the following expressions may be used to correctly describe the temperature (T) variation of the intrinsic carrier density (n_i) of a semiconductor?
- (a) $n_i(T) = (A/T) \exp(-E_g / kT^2)$ (b) $n_i(T) = A(E_g / kT)^{10}$
- (c) $n_i(T) = A \exp(-E_g / 2kT)$ (d) $n_i(T) = AT^{3/2} \exp(-E_g / 2kT)$
58. An intrinsic semiconductor (intrinsic electron density = 10^{16} m^{-3}) is doped with donors to a level of 10^{22} m^{-3} . What is the hole density assuming all donors to be ionized?
- (a) 10^7 m^{-3} (b) 10^8 m^{-3} (c) 10^{10} m^{-3} (d) 10^6 m^{-3} .
59. Consider the following statements in respect of graphite:
1. It has the three coplanar covalent bonds.
 2. It has good electrical and thermal conductivity.
 3. Sheets of graphite are held together by van der waals interaction.
- Which of the statements given above are correct?
- (a) 1, 2 and 3 (b) 1 and 2 (c) 2 and 3 (d) 1 and 3



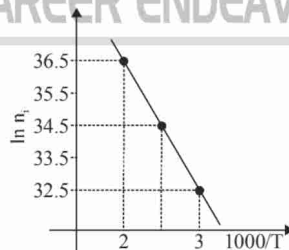
60. A conductor carries a current of 4A and if magnitude of charge of an electron $e = 1.6 \times 10^{-19}$ coulomb, then the number of electrons which flow past the cross section per second is:
 (a) 2.5×10^{19} (b) 1.6×10^{19} (c) 6.04×10^{19} (d) 0.4×10^{19}
61. Which of the following elements act as donor impurities?
 1. Gold 2. Phosphorus 3. Boron 4. Antimony
 5. Arsenic 6. Indium.
 Select the correct answer using the codes given below:
 (a) 1, 2 and 3 (b) 1, 4 and 5 (c) 3, 4, 5 and 6 (d) 2, 4 and 5
62. The conductivity of an intrinsic semiconductor is (symbols have the usual meanings) where e is electron charge
 (a) Generally less than that of a doped semiconductor.
 (b) Given by $\sigma_i = en_i (\mu_n - \mu_p)$
 (c) Given by $\sigma_i = en_i (\mu_n + \mu_p)$ (d) Given by $\sigma_i = n_i (\mu_n + \mu_p)$
63. In an intrinsic semiconductor, as the temperature increases the conductivity σ , electron concentration n , and mobility μ vary as follows:
 (a) σ decreases, n increases and μ decreases (b) σ decreases, n is unaffected and μ decreases
 (c) σ increases, n increases and μ decreases (d) σ increases, n increases and μ is unaffected
64. A Ge semiconductor is doped with acceptor impurity concentration of 10^{15} atoms/cm³. For the given hole mobility of $1800 \text{ cm}^2/\text{V-s}$, the resistivity of this material is:
 (a) $0.288 \Omega \text{ cm}$ (b) $0.694 \Omega \text{ cm}$ (c) $3.472 \Omega \text{ cm}$ (d) $6.944 \Omega \text{ cm}$
65. Identify the CORRECT energy band diagram for silicon doped with Arsenic. Here CB, VB, E_D and E_F conduction band, valence band, impurity level and Fermi level, respectively.



66. For an intrinsic semiconductor, m_e^* and m_h^* are respectively the effective masses of electrons and holes near the corresponding band edges. At a finite temperature, the position of the Fermi level
 (a) Depends on m_e^* but not on m_h^* (b) Depends on m_h^* but not on m_e^*
 (c) Depends on m_e^* and m_h^* (d) depends neither on m_e^* nor on m_h^*
67. An n -type semiconductor is
 (a) positively charged (b) negatively charged
 (c) electrically neutral (d) positively or negatively charged
68. A sample of Si has electron and hole mobilities of 0.13 and $0.05 \text{ m}^2/\text{V-s}$ respectively at 300K . It is doped with P and Al with doping densities of $1.5 \times 10^{21}/\text{m}^3$ and $2.5 \times 10^{21}/\text{m}^3$ respectively. The conductivity of the doped Si sample at 300K is
 (a) $8 \Omega^{-1} \text{ m}^{-1}$ (b) $32 \Omega^{-1} \text{ m}^{-1}$ (c) $20.8 \Omega^{-1} \text{ m}^{-1}$ (d) $83.2 \Omega^{-1} \text{ m}^{-1}$



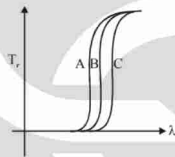
69. A semiconductor has 10^{15} electrons/cm³ ($\mu_e = 5000$ cm²/V.s) and 5×10^{14} holes/cm³ ($\mu_h = 400$ cm²/V.s). If a field of 100V/cm is applied to it, total conductivity is
 (a) $83.2 (\Omega \text{ cm})^{-1}$ (b) $0.832 (\Omega \text{ cm})^{-1}$ (c) $0.832 (\text{m} \Omega \text{ cm})^{-1}$ (d) $8.32 (\text{m} \Omega \text{ cm})^{-1}$
70. The donor concentration in a sample of n-type silicon is increased by a factor of 100. The shift in the position of the Fermi level at 300K, assuming the sample to be non degenerate is _____ meV.
 ($k_B T = 25 \text{ meV}$ at 300K)
71. An electron makes a transition from the valence band to the conduction band in an indirect band gap semiconductor. Which of the following is NOT true?
 (a) The energy of the electron increases (b) A phonon is involved in the process
 (c) A photon is absorbed in the process (d) There is no momentum change in the electron
72. A beam of X-ray of intensity I_0 is incident normally on a metal sheet of thickness 2 mm. The intensity of the transmitted beam is $0.025 I_0$. The linear absorption coefficient of the metal sheet (in m^{-1}) is _____ (upto one decimal places) [GATE 2015]
73. The band gap of an intrinsic semiconductor is $E_g = 0.72$ eV and $m_h^* = 6m_e^*$. At 300K, the Fermi level with respect to the edge of the valence band (in eV) is at _____ (upto three decimal places)
 $k_B = 1.38 \times 10^{-23} \text{ JK}^{-1}$ [GATE 2015]
74. The concentration of electrons, n and holes, p for an intrinsic semiconductor at a temperature T can be expressed as $n = p = AT^{3/2} \exp\left(-\frac{E_g}{2k_B T}\right)$, where E_g is the band gap and A is a constant. If the mobility of both types of carriers is proportional to $T^{-3/2}$, then the log of the conductivity is a linear function of T^{-1} with slope
 (a) $\frac{E_g}{(2k_B)}$ (b) $\frac{E_g}{k_B}$ (c) $\frac{-E_g}{(2k_B)}$ (d) $\frac{-E_g}{k_B}$ [NET June 2015]
75. In an intrinsic semiconductor, the free carrier concentration n (in cm^{-3}) varies with temperature T (in Kelvin) as shown in the figure below. The band gap of the semiconductor is (use Boltzmann constant $k_B = 8.625 \times 10^{-5} \text{ eVK}^{-1}$).



- (a) 1.44 eV (b) 0.72 eV (c) 1.38 eV (d) 0.69 eV
76. In experiment, the resistance of a rectangular slab of a semiconductor is measured as a function of temperature. The semiconductor shows a resistance of 300Ω at 200K and 2Ω at 250 K. Its energy band gap is [Given: $\ln(15) = 2.708$, $\ln(10) = 2.303$]
 (a) 0.138 eV (b) 0.431 eV (c) 0.690 eV (d) 0.862 eV



77. Consider a doped semiconductor having the electron and the hole mobilities μ_0 and μ_p , respectively. Its intrinsic carrier density is n_i . The hole concentration p for which the conductivity is minimum at a given temperature is:
- (a) $n_i \sqrt{\frac{\mu_n}{\mu_p}}$ (b) $n_i \sqrt{\frac{\mu_p}{\mu_n}}$ (c) $n_i \left(\frac{\mu_p}{\mu_n} \right)$ (d) $n_i \left(\frac{\mu_n}{\mu_p} \right)$
78. The longest wavelength that can be absorbed by silicon, which has the band-gap of 1.12 eV, is $1.1 \mu m$. If the longest wavelength that can be absorbed by another material is $0.87 \mu m$, then the bandgap of this material is:
- (a) 1.416 eV (b) 0.886 eV (c) 0.854 eV (d) 0.706 eV
79. A particular green LED emits light of wavelength $5490 \text{ \AA}$. The energy bandgap of the semiconductor material used there is (Planck's constant $= 6.626 \times 10^{-34} \text{ J-s}$):
- (a) 2.26 eV (b) 1.98 eV (c) 1.17 eV (d) 0.74 eV
80. An infra-red LED is usually fabricated from:
- (a) Ge (b) Si (c) Ga As (d) Ga As P
81. Consider the following statements for a photo conducting material:
1. Its dark conductivity is small.
 2. With the absorption of radiation, equal numbers of electrons and of holes are produced.
- Which of the statements given above is/are correct?
- (a) 1 only (b) 2 only (c) Both 1 and 2 (d) Neither 1 nor 2.
82. Photovoltaic devices may be made from various semiconductors as optical materials for which the transmission coefficient (T_r) is shown in the figure given below as a function of photon wavelength.



- Which one of the following is the correct sequence of A, B and C pertaining to Ge, Ga, As and Si, respectively?
- (a) A–B–C (b) B–A–C (c) C–A–B (d) C–B–A
83. The material inside a box is either a metal or a semiconductor. If $R (= 1 \Omega)$ is the resistance of the material, which of the following experiments CANNOT distinguish whether it is a metal or a semiconductor?
- (a) Measurement of R using power supplies of different frequencies.
 (b) Measurement of absorption spectrum in the energy range 0.1 – 2 eV.
 (c) Measurement of R at different temperatures.
 (d) Measurement of R in the presence of different magnetic fields.
84. Photons of energy $1.53 \times 10^{-19} \text{ Joule}$ are incident on a photodiode which has a responsivity of 0.65 A/W. If the optical power level is $10 \mu W$. What is the photo current generated?
- (a) 64 nA (b) 1.5 μA (c) 2.1 μA (d) 6.5 μA
85. An LED made using GaAs emits radiation in:
- (a) Visible region (b) Ultraviolet region
 (c) Infra red region (d) Microwave frequency region.
86. The light emitting diode (LED) emits light of a particular colour because
- (a) It is fabricated from a fluorescent material.
 (b) Transition between energy levels of the carriers takes place while crossing the p-n junction.
 (c) Heat generated in the diode is converted into light.
 (d) The band gap of the semi-conductor material used in fabrication of the diode is equal to the energy $h\nu$ of the light photon.



87. The wavelength of light emitted by a GaAs laser is 8670×10^{-10} m. Given Planck's constant = 6.626×10^{-34} Js, velocity of light = 2.998×10^8 m/s and $1 \text{ eV} = 1.602 \times 10^{-19}$ J, the energy gap in GaAs is
 (a) 0.18 eV (b) 0.7 eV (c) 1.43 eV (d) 2.39 eV
88. An electron of wavevector $\vec{k}_e$, velocity $\vec{v}_e$ and effective mass m_e is removed from a filled energy band. The resulting hole has wavevector $\vec{k}_h$, velocity $\vec{v}_h$, and effective mass m_h . Which one of the following statements is correct?
 (a) $\vec{k}_h = -\vec{k}_e$; $\vec{v}_h = \vec{v}_e$; $m_h = -m_e$ (b) $\vec{k}_h = \vec{k}_e$; $\vec{v}_h = \vec{v}_e$; $m_h = m_e$
 (c) $\vec{k}_h = \vec{k}_e$; $\vec{v}_h = -\vec{v}_e$; $m_h = -m_e$ (d) $\vec{k}_h = -\vec{k}_e$; $\vec{v}_h = \vec{v}_e$; $m_h = m_e$
89. Germanium and silicon photo-sensors have their maximum spectral response in the
 (a) Infrared region (b) Ultraviolet region (c) Visible region (d) X-ray region
90. Light of wavelength 660 nm and power of 1 mW is incident on a semiconductor photodiode with an absorbing layer of thickness of $(\ln 4) \mu\text{m}$.
A. If the absorption coefficient at this wavelength is 10^4 cm^{-1} and if 1% power is lost on reflection at the surface, the power absorbed will be
 (a) 750 μW (b) 675 μW (c) 250 μW (d) 225 μW
B. The generated photo-current for a quantum efficiency of unity will be
 (a) 360 μA (b) 400 μA (c) 133 μA (d) 120 μA
91. The number density of electrons in the conduction band of a semiconductor at a given temperature is $2 \times 10^{19} \text{ m}^{-3}$. Upon lightly doping this semiconductor with donor impurities, the number density of conduction electrons at the same temperature becomes $4 \times 10^{20} \text{ m}^{-3}$. The ratio of majority to minority charge carrier concentration is _____.
[GATE 2016]
92. A *pn* junction was formed with a heavily doped (10^{18} cm^{-3}) *p*-region and lightly doped (10^{14} cm^{-3}) *n*-region. Which of the following statement(s) is(are) correct?
 (a) the width of the depletion layer will be more in *n*-side of the junction
 (b) the width of the depletion layer will be more in the *p*-side of the junction
 (c) the width of the depletion layer will be same on both sides of the junction.
 (d) if the *pn* junction is reverse biased, then the width of the depletion region increases.
93. Consider a 20 μm diameter *p-n* junction fabricated in silicon. the donor density is 10^{16} per cm^3 . The charge developed on the *n*-side is $1.6 \times 10^{-13} \text{ C}$. Then the width (in μm) of the depletion region on the *n*-side of the *p-n* junction is _____.
94. The active medium in a blue LED (Light Emitting Diode) is a $\text{Ga}_x\text{In}_{1-x}\text{N}$ alloy. The band gaps of GaN and InN are 3.5 eV and 1.5 eV respectively. If the band gap of $\text{Ga}_x\text{In}_{1-x}\text{N}$ varies approximately linearly with *x*, the value of *x* required for the emission of blue light of wavelength 400 nm is (take $hc \approx 1200 \text{ eV-nm}$)
 (a) 0.95 (b) 0.75 (c) 0.50 (d) 0.33 **[NET Dec. 2016]**
95. Let I_0 be the saturation current, η the ideality factor and v_F and v_R the forward and reverse potentials, respectively, for a diode. The ratio R_R/R_F of its reverse and forward resistances R_R and R_F respectively, varies as (In the following k_B is the Boltzmann constant, *T* is the absolute temperature and *q* is the charge).
[NET June 2017]
 (a) $\frac{v_R}{v_F} \exp\left(\frac{qv_F}{\eta k_B T}\right)$ (b) $\frac{v_F}{v_R} \exp\left(\frac{qv_F}{\eta k_B T}\right)$ (c) $\frac{v_R}{v_F} \exp\left(-\frac{qv_F}{\eta k_B T}\right)$ (d) $\frac{v_F}{v_R} \exp\left(-\frac{qv_F}{\eta k_B T}\right)$



96. An intrinsic semiconductor of band gap 1.25 eV has an electron concentration 10^{10} cm^{-3} at 300K. Assume that its band gap is independent of the temperature and that the electron concentration depends only exponentially on the temperature. If the electron concentration at 200K is $Y \times 10^N \text{ cm}^{-3}$ ($1 < Y < 10$, $N = \text{integer}$), then the value of N is _____
97. A Germanium diode is operated at a temperature of 27 degree C. The diode terminal voltage is 0.3V when the forward current is 10 mA. What is the forward current (in mA) if the terminal voltage is 0.4V?
(a) 477.3 (b) 577.3 (c) 47.73 (d) 57.73 [JEST 2018]
98. In a pn junction, dopant concentration on the p-side is higher than that on the n-side. Which of the following statement(s) is(are) correct, when the junction is unbiased?
(a) The width of the depletion layer is larger on the n-side
(b) At thermal equilibrium the Fermi energy is higher on the p-side
(c) In the depletion region, number of negative charges per unit area on the p-side is equal to number of positive charges per unit area on the n-side
(d) The value of the built-in potential barrier depends on the dopant concentration
99. A silicon crystal is doped with phosphorus atoms. (The binding energy of a H atom is 13.6 eV, the dielectric constant of silicon is 12 and the effective mass of electron in the crystal is $0.4 m_e$). The gap between the donor energy level and the bottom of the conduction band is nearest to
(a) 0.01 eV (b) 0.08 eV (c) 0.02 eV (d) 0.04 eV [NET Dec. 2018]
100. In a sample of germanium, at a temperature 77 K, optical excitations create an average density of 10^{12} conduction electrons per cm^3 . At this temperature, the electron and hole mobilities are equal, and given by

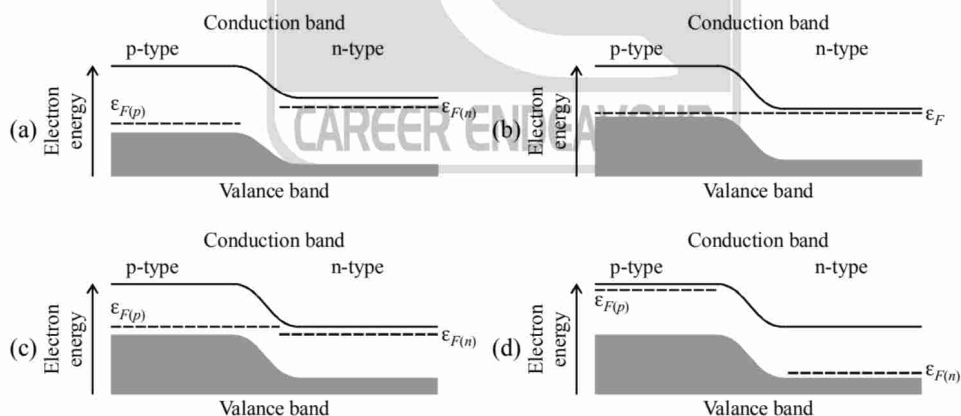
$$\mu = 0.5 \times 10^4 \text{ cm}^2 \text{ s}^{-1} \text{ V}^{-1}$$

The value of the Einstein diffusion coefficient for the electrons and holes is

[TIFR 2019]

- (a) $1.65 \times 10^{-3} \text{ m}^2 \text{ s}^{-1}$ (b) $3.3 \times 10^{-2} \text{ m}^2 \text{ s}^{-1}$ (c) $3.3 \times 10^{-3} \text{ m}^2 \text{ s}^{-1}$ (d) $6.6 \times 10^{-3} \text{ m}^2 \text{ s}^{-1}$

101. For a forward biased p-n junction diode, which one of the following energy-band diagrams is correct?



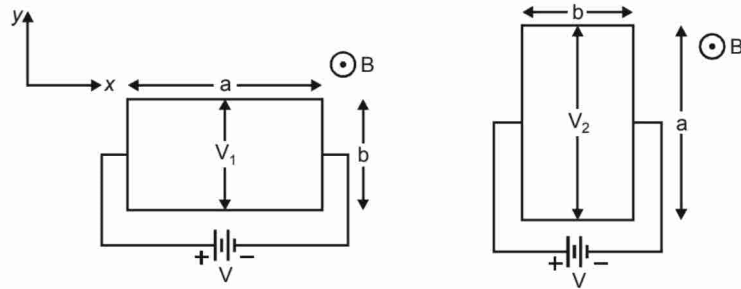
102. A bound electron and hole pair interacting via Coulomb interaction in a semiconductor is called an exciton. The effective masses of an electron and a hole are about $0.1 m_e$ and $0.5 m_e$ respectively, where m_e is the rest mass of the electron. The dielectric constant of the semiconductor is 10. Assuming that the energy levels of the excitons are hydrogen like, the binding energy of an exciton (in units of the Rydberg constant) is closest to
(a) 2×10^{-3} (b) 2×10^{-4} (c) 8×10^{-4} (d) 3×10^{-3} [NET June 2019]



103. Consider a metal which obeys the Sommerfeld model exactly. If E_F is the Fermi energy of the metal at $T = 0\text{K}$ and R_H is its Hall coefficient, which of the following statements is correct? [GATE 2016]
- (a) $R_H \propto E_F^{3/2}$ (b) $R_H \propto E_F^{2/3}$
 (c) $R_H \propto E_F^{-3/2}$ (d) R_H is independent of E_F
104. The majority carriers in n-type semiconductor have an average drift velocity V in a direction perpendicular to a uniform magnetic field B . The electric field E induced due to Hall effects acts in the direction:
- (a) $V \times B$ (b) $B \times V$ (c) along V (d) opposite to V
105. Hall effect is observed in a specimen when it (metal or a semiconductor) is carrying current and is placed in a magnetic field. The resultant electric field inside the specimen will be in
- (a) A direction normal to both current and magnetic field.
 (b) The direction of current
 (c) A direction antiparallel to magnetic field
 (d) An arbitrary direction depending upon the conductivity of the specimen.
106. A doped Germanium crystal of length 2 cm, breadth 1 cm and width 1 cm, carries a current of 1 mA along its length parallel to +x axis. A magnetic field of 0.5 T is applied along +z axis. Hall voltage of 6 mV is measured with negative polarity at $y = 0$ plane. The sign and concentration of the majority charge carrier are, respectively [Given : $e = 1.6 \times 10^{-19} \text{C}$]
- (a) Positive and $5.2 \times 10^{19} \text{m}^{-3}$
 (b) Negative and $5.2 \times 10^{19} \text{m}^{-3}$
 (c) Positive and $10.4 \times 10^{19} \text{m}^{-3}$
 (d) Negative and $10.4 \times 10^{19} \text{m}^{-3}$
107. In an extrinsic semiconductor the Hall coefficient R_H
- (a) Increases with increase of temperature (b) Decreases with increase of temperature
 (c) Is independent of the change of temperature (d) Changes with the change of magnetic field.
108. Which of the following statements related to the Hall effect?
1. A potential difference is developed across a current-carrying metal strip when the strip is placed in a transverse magnetic field.
 2. The Hall effect is very weak in metals but is large in semiconductors
 3. The Hall effect is very weak in semiconductors but is large in metals.
 4. It is applied in the measurement of the magnetic field intensity.
- Select the correct answer using the code given below:
- (a) 1, 2 and 3 (b) 2 and 4 (c) 1, 3 and 4 (d) 1, 2 and 4
109. Measurement of Hall effect coefficient in a semiconductor provides information on the
- (a) Sign and mass of charge carriers (b) Mass and concentration of charge carriers
 (c) Sign of charge carriers alone (d) Sign and concentration of charge carriers.

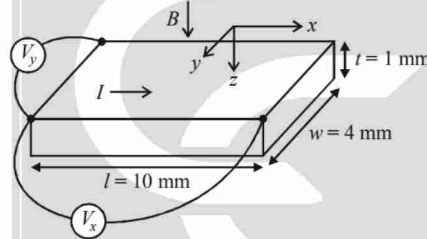


110. A thin rectangular conducting plate of length a and width b is placed in the xy -plane in two different orientations, as shown in the figures below. In both cases a magnetic field B is applied in the z -direction and a current flows in the x -direction due to the applied voltage V . [NET Dec. 2016]

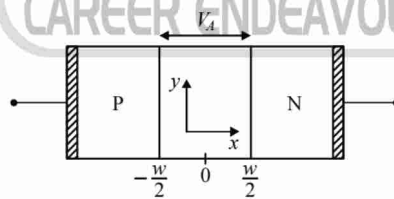


If the Hall voltage across the y -direction in the two cases satisfy $V_2 = 2V_1$, the ratio $a : b$ must be

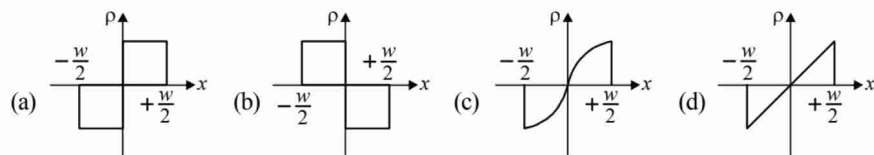
- (a) 1 : 2 (b) $1 : \sqrt{2}$ (c) 2 : 1 (d) $\sqrt{2} : 1$
111. A p -doped semiconductor slab carries a current $I = 100$ mA in a magnetic field $B = 0.2$ T as shown. One measures $V_y = 0.25$ mV and $V_x = 2$ mV. The mobility of holes in the semiconductor is _____ $\text{m}^2\text{V}^{-1}\text{s}^{-1}$ (up to two decimal places). [GATE 2018]



112. A pn -junction diode has a linearly graded doping profile given by $N_D - N_A = ax$, where $a > 0$ is constant, N_D is the donor density and N_A is the acceptor density, with the x -axis along the sample with the origin at its centre, as shown in the figure. [NET Dec. 2019]



The figure that best represents the charge density profile in the depletion region along the x -direction, is



113. Consider a two-dimensional material of length l and width w subjected to a constant magnetic field B applied perpendicular to it. The number of charge carriers per unit area may be expressed as

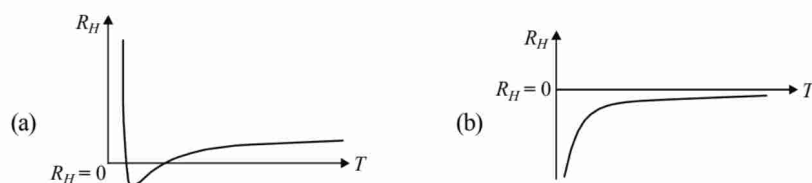
$$n = \frac{k|q|B}{(2\pi\hbar)},$$

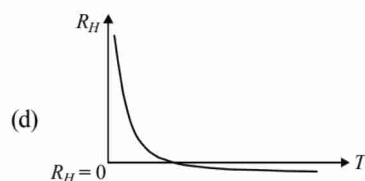
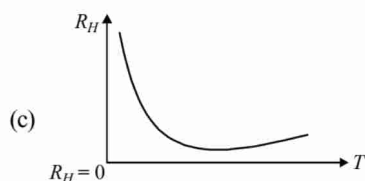
where k is a positive real number and q is the carrier charge. Then the Hall resistivity ρ_{xy} is

- (a) $\frac{2\pi\hbar k}{q^2} \sqrt{\frac{l}{w}}$ (b) $\frac{2\pi\hbar}{kq^2} \sqrt{\frac{w}{l}}$ (c) $\frac{2\pi\hbar}{kq^2}$ (d) $\frac{2\pi\hbar k}{q^2}$ [NET Dec. 2017]
114. In the Hall effect the sign of the Hall voltage depends upon the carrier concentration (n, p) and mobility (μ_n, μ_p) of electrons and holes, respectively. The Hall voltage in intrinsic and n-type semiconductors is negative because
 (a) $n\mu_n > p\mu_p$ (b) $n > p, \mu_n < \mu_p$ (c) $n > p, \mu_n = \mu_p$ (d) $n = p, \mu_n > \mu_p$
115. In an experiment to measure the Hall co-efficient of a particular sample, the generated Hall voltage was found to be too small to measure. To improve the measurement, you would
 (a) Increase the magnetic field (b) Increase the temperature of the sample
 (c) Use a longer and thinner sample (d) Use a shorter and thicker sample.
116. A magnetic field sensor based on the Hall effect is to be fabricated by implanting. As into a Si film of thickness $1 \mu\text{m}$. The specifications require a magnetic field sensitivity of 500 mV/Tesla at an excitation current of 1 mA . The implantation dose is to be adjusted such that the average carrier density, after activation, is
 (a) $1.25 \times 10^{26} \text{ m}^{-3}$ (b) $1.25 \times 10^{22} \text{ m}^{-3}$ (c) $4.1 \times 10^{21} \text{ m}^{-3}$ (d) $4.1 \times 10^{20} \text{ m}^{-3}$
117. In a Hall effect experiment, the Hall voltage for an intrinsic semiconductor is negative. This is because (symbols carry usual meaning). [GATE 2015]
 (A) $n \approx p$ (B) $n > p$ (C) $\mu_e > \mu_h$ (D) $m_e^* > m_h^*$
 (a) A (b) B (c) C (d) D
118. The Hall coefficient of a Si wafer was found to be $-7.35 \times 10^{-5} \text{ m}^3 \text{C}^{-1}$ in the temperature range from 100 to 400 K . The type of charge carrier and the approximate value of carrier density respectively are
 (a) n-type; $8.5 \times 10^{22} \text{ m}^{-3}$ (b) p-type; $8.5 \times 10^{22} \text{ m}^{-3}$
 (c) n-type; $4.2 \times 10^{22} \text{ m}^{-3}$ (d) p-type; $4.2 \times 10^{22} \text{ m}^{-3}$
119. A silicon wafer of thickness $200 \mu\text{m}$ is doped with 10^{23} phosphorus atoms per m^3 . If the sample is kept in a field of 0.2 Weber/m^2 and a current of 1 mA is passed through the sample, the Hall voltage produced is
 (a) $-6.25 \mu\text{V}$ (b) $6.25 \mu\text{V}$ (c) $-62.5 \mu\text{V}$ (d) $62.5 \mu\text{V}$
120. The Hall co-efficient for a semiconductor having both types of carriers is given as: [NET Dec. 2019]

$$R_H = \frac{p\mu_p^2 - n\mu_n^2}{|e|(p\mu_p + n\mu_n)^2}$$

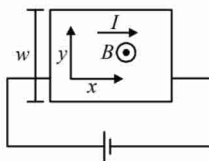
where p and n are the carrier densities of the holes and electrons, μ_p and μ_n are their respective mobilities. For a p -type semiconductor in which the mobility of holes is less than that of electrons, which of the following graphs best describes the variation of the Hall coefficient with temperature?



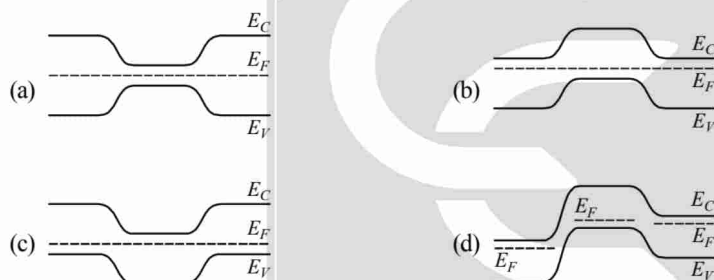


121. A surface current I flows in a rectangular conducting sheet of width w and a carrier density of n particles per unit area. The charge of the carriers is q . When a constant magnetic field $B\hat{k}$ is applied perpendicular to the sheet and coming out of it (see the figure below), the y -component of the induced electric field in the sheet, away from the edges, is

[NET Dec. 2019]



- (a) $\frac{q^2 I}{nB}$ (b) $-\frac{q^2 I}{nB}$ (c) $\frac{IB}{qnw}$ (d) $-\frac{IB}{qnw}$
122. For an unbiased Silicon n - p - n transistor in thermal equilibrium, which one of the following, electronic energy band diagrams is correct? (E_C = conduction band minimum, E_V = valence band maximum, E_F = Fermi level).



CAREER ENDEAVOUR



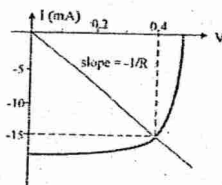


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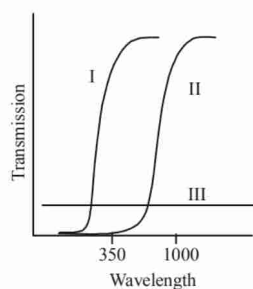
SOLID STATE PHYSICS

Assignment-5

- Monochromatic light of wavelength 660 nm and intensity 100 mW/cm^2 falls on a solar cell of area 30 cm^2 . The conversion efficiency of the solar cell is 10%. If each converted photon results in an electron-hole pair, what is the maximum circuit current supplied by the solar cell? (Take $h = 6.6 \times 10^{-34} \text{ J-s}$, $c = 3 \times 10^8 \text{ m/s}$ and $e = 1.6 \times 10^{-19} \text{ C}$).
 (a) 160 mA (b) 320 mA (c) 1600 mA (d) 3200 mA
- The I-V characteristics of a solar cell of dimension $1 \text{ cm} \times 1 \text{ cm}$ illuminated with light of intensity 600 Wm^{-2} are shown in the figure. If the cell is used to drive a load R (see the load line in the figure) the efficiency of the solar cell is:



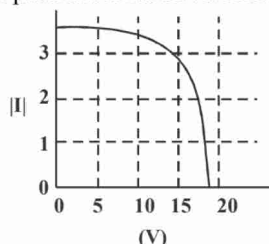
- (a) 1% (b) 5% (c) 20% (d) 10%
- An LED operates at 1.5 V and 5 mA in forward bias. Assuming an 80% external efficiency of the LED, how many photons are emitted per second?
 (a) 5.0×10^{16} (b) 1.5×10^{16} (c) 0.8×10^{16} (d) 2.5×10^{16}
- The experimentally measured transmission spectra of metal, insulator and semiconductor thin films are shown in the figure. It can be inferred that I, II and III correspond respectively, to



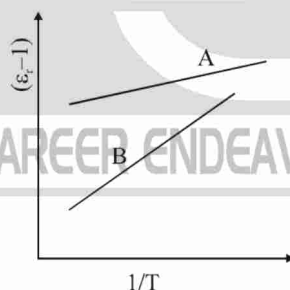
- (a) insulator, semiconductor and metal (b) semiconductor, metal and insulator
 (c) metal, semiconductor and insulator (d) insulator, metal and semiconductor



5. The output characteristics of a solar panel at a certain level of irradiance is shown in the figure below.



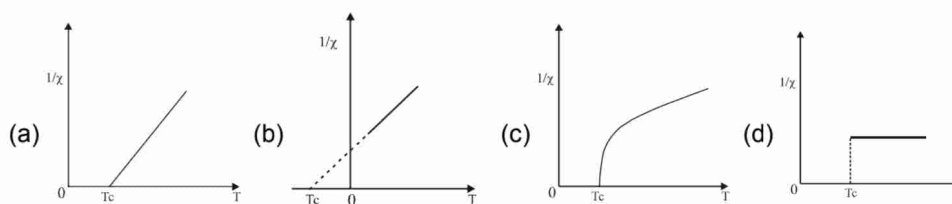
- If the solar cell is to power a load of $5\ \Omega$, the power drawn by the load is:
 (a) 97 W (b) 73 W (c) 50 W (d) 45 W
6. If the gap between ground state and excited state energy levels of electrons in an atom is 1 eV. Estimate the wavelength of the light the atom will absorb? The value of the Planck's constant is 6.6×10^{-34} Js.
 (a) 1 mm (b) $1.24\ \mu\text{m}$ (c) 1.24 angstrom (d) 1 cm
7. The difference between the electron and hole of a semiconductor laser is 1.5 eV and the band gap of the semiconductor is 1.43 eV. The upper and lower frequency limits of the laser will be respectively
 (a) 3.3×10^{14} and 9.9×10^{13} Hz (b) 3.7×10^{14} and 3.5×10^{14} Hz
 (c) 6.28×10^{14} and 3.1×10^{14} Hz (d) 1.16×10^{15} and 8.97×10^{14} Hz
8. The power density of sunlight incident on a solar cell is $100\ \text{mW}/\text{cm}^2$. Its short circuit current density is $30\ \text{mA}/\text{cm}^2$ and the open circuit voltage is 0.7 V. If the fill factor of the solar cell decreases from 0.8 to 0.5 then the percentage efficiency will decrease from
 (a) 42.0 to 26.2 (b) 24.0 to 16.8 (c) 21.0 to 10.5 (d) 16.8 to 10.5
9. Two dielectric materials A and B exhibit both ionic and orientational polarizabilities. The variation of the dielectric constant $\epsilon (= \epsilon_r - 1)$ with temperature T is shown in the figure, where ϵ_r is the relative dielectric constant. It can be inferred from the figure that:



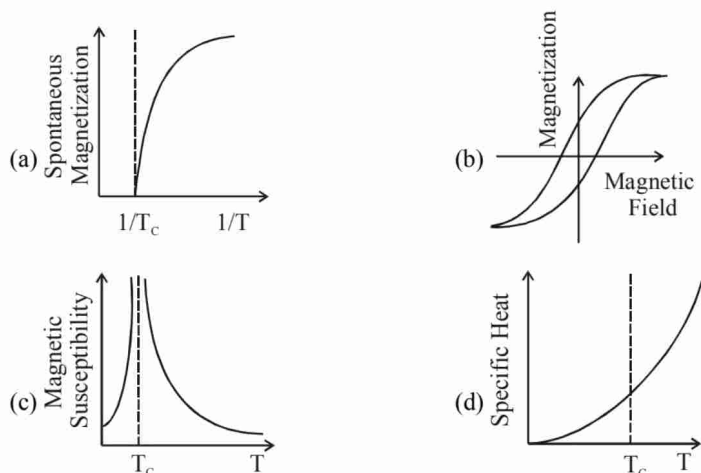
- (a) A is more polar and it has a smaller value of ionic polarizability than that of B
 (b) A is more polar and it has a higher value of ionic polarizability than that of B
 (c) B is more polar and it has a higher value of ionic polarizability than that of A
 (d) B is more polar and it has a smaller value of ionic polarizability than that of A
10. If the static dielectric constant of NaCl crystal is 5.6 and its optical refractive index is 1.5, the ratio of its electric polarizability to its total polarizability is:
 (a) 0.5 (b) 0.7 (c) 0.8 (d) 0.9
11. The dielectric constant of a material at optical frequencies is mainly due to
 (a) Ionic polarizability. (b) Electronic polarizability
 (c) Dipolar polarizability (d) Ionic and dipolar polarizability.



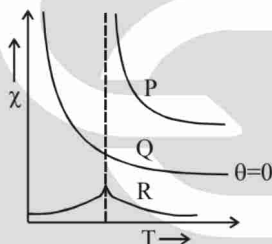
12. Magnetic long range order is typically exhibited by:
 (a) noble metals (b) alkali metals
 (c) inert gas solids (d) transition metals
13. Which one of the following is TRUE for a semiconductor p–n junction with no external bias?
 (a) The total charge in the junction is not conserved
 (b) The p side of the junction is positively charged
 (c) The p side of the junction is negatively charged
 (d) No charge develops anywhere in the junction
14. Identify which one is a first order phase transition?
 (a) A liquid to gas transition at its critical temperature.
 (b) A liquid to gas transition close to its triple point.
 (c) A paramagnetic to ferromagnetic transition in the absence of a magnetic field.
 (d) A metal to superconductor transition in the absence of a magnetic field.
15. A second order phase transition is one in which:
 (a) the plot of entropy as a function of temperature shows a discontinuity
 (b) the plot of specific heat as a function of temperature shows a discontinuity
 (c) the plot of volume as a function of pressure shows a discontinuity
 (d) the plot of compressibility as a function of temperature is continuous
16. A ferromagnetic material has a Curie temperature 100 K. Then:
 (a) its susceptibility is double when it is cooled from 300 K to 200 K
 (b) all the atomic magnets in it get oriented in the same direction above 100 K
 (c) the plot of inverse susceptibility versus temperature is linear with a slope T_C
 (d) the plot of its susceptibility versus temperature is linear with an intercept T_C
17. When liquid oxygen is poured down close to a strong bar magnet, the oxygen stream is:
 (a) repelled towards the lower field because it is diamagnetic
 (b) attracted towards the higher field because it is diamagnetic
 (c) repelled towards the lower field because it is paramagnetic
 (d) attracted towards the higher field because it is paramagnetic
18. A ferromagnetic mixture of iron and copper having 75% atoms of Fe exhibits a saturation magnetization of $1.3 \times 10^6 \text{ A m}^{-1}$. Assume that the total number of atoms per unit volume is $8 \times 10^{28} \text{ m}^{-3}$. The magnetic moment of an iron atom, in terms of the Bohr Magnetron, is:
 (a) 1.7 (b) 2.3 (c) 2.9 (d) 3.8
19. The plot of inverse magnetic susceptibility $\frac{1}{\chi}$ versus temperature T of an antiferromagnetic sample corresponds to:



20. In an experiment involving a ferromagnetic medium, the following observations were made. Which one of the plots does NOT correctly represent the property of the medium? (T_c is the Curie temperature)



21. The dependence of the magnetic susceptibility (χ) of a material with temperature (T) can be represented by $\chi \propto \frac{1}{T - \theta}$, where θ is the Curie-Weiss temperature. The plot of magnetic susceptibility versus temperature is sketched in the figure, as curves P, Q and R with curve Q having $\theta = 0$. Which one of the following statements is correct?



- (a) Curve R represents a paramagnet and Q a ferromagnet.
 (b) Curve Q represents a ferromagnet and P an antiferromagnet.
 (c) Curve R represents an antiferromagnet and Q a paramagnet.
 (d) Curve R represents an antiferromagnet and Q a ferromagnet.
22. The temperature (T) dependence of magnetic susceptibility (χ) of a ferromagnetic substance with a Curie temperature (T_c) is given by

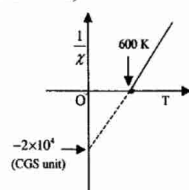
- (a) $\frac{C}{T - T_c}$, for $T < T_c$ (b) $\frac{C}{T - T_c}$, for $T > T_c$
 (c) $\frac{C}{T + T_c}$, for $T > T_c$ (d) $\frac{C}{T + T_c}$, for all temperature.

23. Assume that the free energy of a magnetic system has an expansion in the order parameter M of the form $F(M, T) = a(T - T_c)M^2 + bM^4 + cM^6$, with a , b and $c > 0$. As the temperature is lowered below T_c , the system undergoes a phase transition. The behaviour of the order parameter just below the transition, where $(T - T_c)$ is very small, is best described by

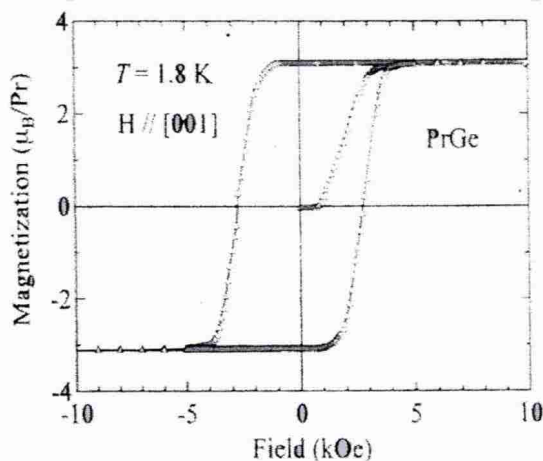
- (a) $M \propto (T_c - T)^{-1/2}$ (b) $M \propto (T_c - T)^{1/2}$ (c) $M \propto (T_c - T)$ (d) $M \propto (T_c - T)^3$



24. The magnetization M of a system in equilibrium at temperature T is given by the equation $M = \tanh\left(\frac{M}{T}\right)$, where all quantities are in dimensionless units. This system will show
- (a) a first order phase transition at $T = 1$ (b) a second order phase transition at $T = 1$
 (c) no phase transition at any T (d) a second order phase transition at $T = \frac{1}{2}$.
25. The (Pauli) paramagnetic susceptibility of a metal at a low temperature T is
- (a) proportional to T (b) independent of T (c) proportional to T^2 (d) proportional to T
26. Inverse susceptibility ($1/\chi$) as a function of temperature, T for a material undergoing paramagnetic to ferromagnetic transition is given in the figure, where O is the origin. the values of the Curie constant, C and the Weiss molecular field constant, λ , in CGS units, are



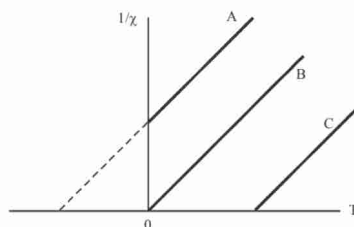
- (a) $C = 5 \times 10^{-5}$, $\lambda = 3 \times 10^{-2}$ (b) $C = 3 \times 10^{-2}$, $\lambda = 5 \times 10^{-5}$
 (c) $C = 3 \times 10^{-2}$, $\lambda = 2 \times 10^{-4}$ (d) $C = 2 \times 10^4$, $\lambda = 3 \times 10^{-2}$
27. The magnetization M of a ferromagnet, as a function of the temperature T and the magnetic field H , is described by the equation $M = \tanh\left(\frac{T_c}{T}M + \frac{H}{T}\right)$. In these units, the zero-field magnetic susceptibility in terms of $M(0) = M(H=0)$ is given by
- (a) $\frac{1 - M^2(0)}{T - T_c(1 - M^2(0))}$ (b) $\frac{1 - M^2(0)}{T - T_c}$ (c) $\frac{1 - M^2(0)}{T + T_c}$ (d) $\frac{1 - M^2(0)}{T}$
28. The Curie temperature of a single crystal of PrGe is known to be 41 K. The magnetization data of this sample is measured at 1.8 K for the magnetic field applied parallel to the [001] direction is shown in the figure on the left. At a temperature of 38 K, the hysteresis loop in the figure will



- (a) Have the same width (b) decrease in width
 (c) increase in width (d) shrink to a line.



29. The magnetic susceptibility χ of three samples A, B and C, is measured as a function of their absolute temperature T, leading to the graphs shown below.



From these graphs, the magnetic nature of the samples can be inferred to be

- (a) A: anti-ferromagnet B: paramagnet C: ferromagnet
 (b) A: diamagnet B: paramagnet C: anti-ferromagnet
 (c) A: paramagnet B: anti-ferromagnet C: ferromagnet
 (d) A: anti-ferromagnet B: diamagnet C: paramagnet.
30. The following are the plots of the temperature dependence of the magnetic susceptibility for three different samples. [JAM 2010]

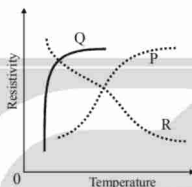


The plots A, B and C correspond to

- (a) Ferromagnet, paramagnet and diamagnet, respectively.
 (b) Paramagnet, diamagnet and ferromagnet, respectively
 (c) Ferromagnet, diamagnet and paramagnet, respectively
 (d) Diamagnet, paramagnet and ferromagnet, respectively.
31. The physical phenomenon that cannot be used for memory storage applications is
 (a) large variation in magnetoresistance as a function of applied magnetic field
 (b) variation in magnetization of a ferromagnet as a function of applied magnetic field
 (c) variation in polarization of a ferroelectric as a function of applied electric field
 (d) variation in resistance of a metal as a function of applied electric field
32. For Nickel, the number density is 8×10^{23} atoms/cm³ and electronic configuration is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^8 4s^2$. The value of the saturation magnetization of Nickel in its ferromagnetic states is _____ $\times 10^9$ A/m. (Given the value of Bohr magneton $\mu_B = 9.21 \times 10^{-21}$ Am²)
33. A solid material is found to have a temperature independent magnetic susceptibility, $\chi = C$. Which of the following statements is correct? [GATE 2016]
 (a) If C is positive, the material is a diamagnet
 (b) If C is positive, the material is a ferromagnet
 (c) If C is negative, the material could be a type I superconductor
 (d) If C is positive, the material could be a type I superconductor
34. In the Meissner state the magnetic susceptibility of a super conductor in S.I. units is:
 (a) $-\frac{1}{4\pi}$ (b) $\frac{1}{4\pi}$ (c) -1 (d) $-\frac{1}{\mu_a}$



35. Which one of the following statements about superconductors is NOT true?
- A type I superconductor is completely diamagnetic
 - All type II superconductor exhibits Meissner effect upto second critical magnetic field (H_{C_2}).
 - A type II superconductor exhibits zero resistance upto the second critical magnetic field
 - Both type I and type II superconductors exhibit sharp fall in resistance at the superconducting transition temperature.
36. A solid superconductor is placed in an external magnetic field and then cooled below its critical temperature. The superconductor.
- retains its magnetic flux because the surface current supports it.
 - expels out its magnetic flux because it behaves like a paramagnetic material.
 - expels out its magnetic flux because it behaves like an anti-ferromagnetic material
 - expels out its magnetic flux because the surface current induces a field in the direction opposite to the applied magnetic field.
37. Variation of electrical resistivity r with temperature T of three solids is sketched (on different scales) in the figure, as curves P, Q and R.



Which of the following statements describes the variations most appropriately?

- P is for a superconductor and R for a semiconductor
 - Q is for a superconductor and P for a conductor
 - Q is for a superconductor and R for a conductor
 - R is for a superconductor, and P for a conductor
38. The critical magnetic field for a solid in superconducting state
- Does not depend upon temperature
 - Increases if the temperature increases
 - Increases if the temperature decreases
 - Does not depend on the transition temperature.
39. Which one of the following statements is NOT TRUE?
- Entropy decreases markedly on cooling a superconductor below the critical temperature, T_c .
 - The electronic contribution to the heat capacity in the superconducting state has an exponential form with an argument proportional to T^{-1} , suggestive of an energy gap
 - A type I superconductor is a perfect diamagnet.
 - Critical temperature of superconductors does not vary with the isotopic mass.
40. A superconducting ring is cooled in the presence of a magnetic field below its critical temperature (T_c). The total magnetic flux that passes through the ring is:
- zero
 - $n \frac{h}{2e}$
 - $\frac{nh}{4\pi e}$
 - $\frac{ne^2}{hc}$
41. Experimental study shows that there exists an energy gap in a superconductor. Which one of the following statements is incorrect?
- The gap separates the lowest excited state in a superconductor from the ground state.
 - The temperature dependence of electronic specific heat indicates the existence of an energy gap.
 - The existence of an energy gap is accounted for in the BCS theory.
 - The energy gap in superconductors is similar to the energy gap which occurs in insulators.



42. An external magnetic field of magnitude H is applied to a Type-I superconductor at a temperature below the transition point. Then which one of the following statements is NOT true for H less than the critical field H_c ?
- the sample is diamagnetic
 - its magnetization varies linearly with H
 - the lines of magnetic induction are pushed out from the sample
 - the sample exhibits mixed states of magnetization near H_c
43. The thermal conductivity of a given material reduces when it undergoes a transition from its normal state to the superconducting state. The reason is:
- The Cooper pairs cannot transfer energy to the lattice.
 - Upon the formation of Cooper pairs, the lattice becomes less efficient in heat transfer.
 - The electrons in the normal state lose their ability to transfer heat because of their coupling to the Cooper pairs.
 - The heat capacity increases on transition to the superconducting state leading to a reduction in thermal conductivity.
44. A flux quantum (fluxoid) is approximately equal to 2×10^{-7} gauss-cm². A type II superconductor is placed in a small magnetic field, which is then slowly increased till the field starts penetrating the superconductor. The strength of the field at this point is $\frac{2}{\pi} \times 10^5$ gauss
- A. The penetration depth of this superconductor is
- 100 Å
 - 10 Å
 - 1000 Å
 - 314 Å
- B. The applied field is further increased till superconductivity is completely destroyed. The strength of the field is now $\frac{8}{\pi} \times 10^5$ gauss. The correlation length of the superconductor is:
- 20 Å
 - 200 Å
 - 628 Å
 - 2000 Å
45. Let ξ and λ denote the coherence length and the penetration depth of a superconductor. For a type-I superconductor
- $\xi < \lambda$
 - $\xi > \lambda$
 - $\xi = \lambda$
 - $\lambda = 0$
46. The magnetic susceptibility of a type I superconductor at a temperature T below the transition temperature T_c
- increases linearly from a negative value to zero as temperature increases from 0 to T_c
 - decreases linearly from a positive value to zero as temperature increases from 0 to T_c
 - is negative and constant at all T
 - is positive and constant at all T
47. The isotope effect in superconductors says that the critical temperature
- increases as the isotopic mass increases
 - decreases as the isotopic mass increases
 - increases linearly with the isotopic mass
 - decreases linearly with the isotopic mass.
48. Considering the BCS theory of superconductors, which one of the following statements is NOT CORRECT? (h is the Planck's constant and e is the electronic charge)
- Presence of energy gap at temperatures below the critical temperature
 - Different critical temperatures for isotopes
 - Quantization of magnetic flux in superconducting ring in the unit of (h/e)
 - Presence of Meissner effect

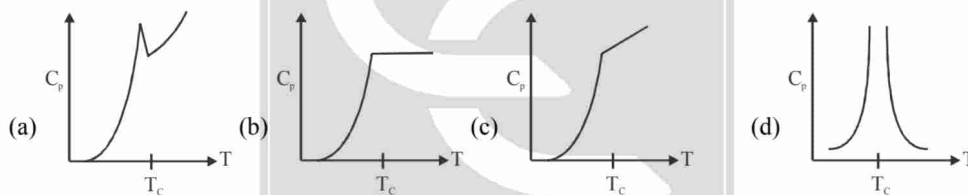


49. **Group-I** contains elementary excitations in solids. **Group-II** gives the associated fields with these excitations. MATCH the excitations with their associated field and select your answer as per codes given below.

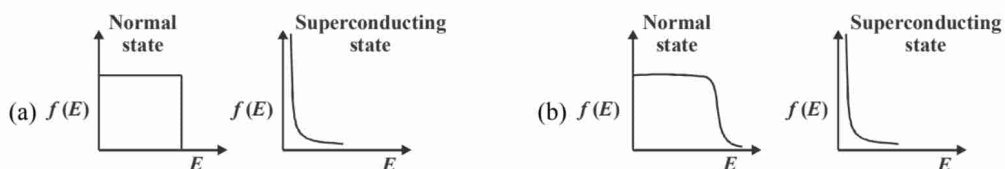
Group-I	Group-II
(P) phonon	(i) photon + lattice vibration
(Q) plasmon	(ii) electron + elastic deformation
(R) polaron	(iii) collective electron oscillations
(S) polariton	(iv) elastic wave

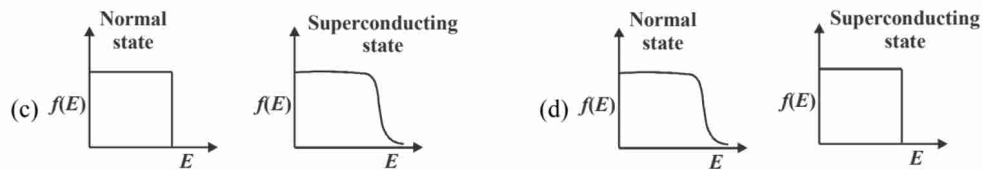
Codes:

- (a) (P-iv), (Q-iii), (R-i), (S-ii) (b) (P-iv), (Q-iii), (R-ii), (S-i)
 (c) (P-i), (Q-iii), (R-ii), (S-iv) (d) (P-iii), (Q-iv), (R-ii), (S-i)
50. The order of magnitude of the energy gap of a typical superconductor is:
 (a) 1 MeV (b) 1 KeV (c) 1 eV (d) 1 meV
51. The voltage required to produce 483.6 MHz through a Josephson junction is
 (a) 1 nV (b) 1 μ V (c) 1 mV (d) 1 V
52. The transition temperature of a BCS superconductor with an average atomic mass of 199.5 is 4.185K. What is the transition temperature for an average atomic mass of 203.4?
 (a) 4.185 (b) 4.145 (c) 4.226 (d) 4.105
53. A solid sample has the property that, when cooled below a certain temperature, it expels any small applied magnetic field from within the material. Which of the following best describes this sample in the cooled state?
 (a) Paramagnet (b) Diamagnet (c) Ferromagnet (d) Anti-ferromagnet
54. The plot of specific heat versus temperature across the superconducting transition temperature (T_C) is most appropriately represented by



55. A superconducting ring carries a steady current in the presence of a magnetic field $\vec{B}$ normal to the plane of the ring. Identify the incorrect statement.
- (a) The flux passing through the superconductor is quantized in units of hc/e
 (b) The current and the magnetic field in the superconductor are time independent
 (c) The current density $\vec{J}$ and $\vec{B}$ are related by the equation $\vec{\nabla} \times \vec{J} + \Lambda^2 \vec{B} = 0$, where Λ is a constant
 (d) The superconductor shows an energy gap which is proportional to the transition temperature of the superconductor
56. Which one of the following represents the electron occupancy for a superconductor in its normal and superconducting states? **[GATE 2015]**





57. The critical magnetic fields of a super-conductor at temperatures 4 K and 8 K are 11 mA/m and 5.5 mA/m respectively. The transition temperature is approximately [NET June 2015]
 (a) 8.4 K (b) 10.6 K (c) 12.9 K (d) 15.0 K
58. A DC voltage V is applied across a Josephson junction between two superconductors with a phase difference ϕ_0 . If I_0 and k are constants that depend on the properties of the junction, the current flowing through it has the form
 (a) $I_0 \sin\left(\frac{2eVt}{\hbar} + \phi_0\right)$ (b) $kV \sin\left(\frac{2eVt}{\hbar} + \phi_0\right)$ (c) $kV \sin \phi_0$ (d) $I_0 \sin \phi_0 + kV$
59. The high temperature magnetic susceptibility of solids having ions with magnetic moments can be described by

$$\chi \propto \frac{1}{T + \theta}$$
 where T as absolute temperature and θ as constant. The three behaviors i.e., paramagnetic, ferromagnetic and anti-ferromagnetic are described, respectively, by [GATE 2018]
 (a) $\theta < 0, \theta > 0, \theta = 0$ (b) $\theta > 0, \theta < 0, \theta = 0$
 (c) $\theta = 0, \theta < 0, \theta > 0$ (d) $\theta = 0, \theta > 0, \theta < 0$
60. A conventional type-I superconductor has a critical temperature of 4.7 K at zero magnetic field and a critical field in Tesla at 2 K (rounded off to three decimal place) _____. [GATE 2019]
61. The relative magnetic permeability of a type-I superconductor is [GATE 2019]
 (a) 0 (b) -1 (c) 2π (d) $1/4\pi$
62. In the AC Josephson effect, a supercurrent flows across two superconductors separated by a thin insulating layer and kept at an electric potential difference ΔV . The angular frequency of the resultant supercurrent is given by
 (a) $\frac{2e\Delta V}{\hbar}$ (b) $\frac{e\Delta V}{\hbar}$ (c) $\frac{e\Delta V}{\pi\hbar}$ (d) $\frac{e\Delta V}{2\pi\hbar}$